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(NASA-RP-1243) LIMB-DARKENING FUNCTIONS AS  
DERIVED FROM ALONG-TRACK OPERATION OF THE  
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## Abstract

*During August 1985, the scanning radiometers of the Earth Radiation Budget Experiment aboard the Earth Radiation Budget Satellite (ERBS) and the NOAA-9 satellite were operated in along-track scanning models. These data have been analyzed to produce limb-darkening models for Earth-emitted radiation, which relates the radiance in any given direction to the radiant exitance. Limb-darkening models are presented in tabular form and are shown as figures for day and night for each spacecraft. The scene types were computed with measurements within  $10^\circ$  of zenith. The models have values near zenith of 1.02 to 1.09, with values near 1.06 being typical. The typical value of the model is 1.06 for both day and night for ERBS, and the typical value at zenith is 1.06 for day and 1.05 for night for NOAA-9. Mean models are formed for the ERBS and for the NOAA-9 results and are found to differ less than 1 percent, with the ERBS results being the higher. The models vary about 1 percent with latitude near zenith. The present paper is a companion paper to NASA Reference Publication 1214, which reported limb-darkening models derived from January 1985 along-track operation of the scanning radiometer aboard the ERBS.*

## Introduction

The interpretation of satellite measurements of longwave radiation, which is earth-emitted radiation and in the spectral range 5 to 50  $\mu\text{m}$ , requires the use of limb-darkening functions. The need for these functions has been recognized from the beginning of studies of outgoing longwave radiation by use of satellites (Wark, Yamamoto, and Lienesch 1962). Longwave radiance from a region decreases with increasing zenith angle of the ray due to the increasing path length through the cooler upper layers of the atmosphere. Limb-darkening functions describe this variation in longwave radiance with zenith angle, and are necessary for relating radiance measurements to radiant exitances from the Earth-atmosphere system. The limb-darkening models used for the analysis of scanning radiometer data from the Earth Radiation Budget Experiment (ERBE) were developed by Taylor and Stowe (1984 and 1986) and were extended by Suttles et al. (1989).

The Earth Radiation Budget Experiment (ERBE) included scanning radiometers on the NOAA-9 and NOAA-10 operational meteorological satellites, which are in Sun-synchronous orbits, and a scanning radiometer aboard a dedicated spacecraft, the Earth Radiation Budget Satellite (ERBS), which is in a precessing orbit with  $57^\circ$  inclination (Barkstrom and Smith 1986). The scanning radiometer aboard the ERBS was rotated in azimuth to scan along track, that is, in the orbit plane, from approximately 1900 hours January 16, 1985, to 2100 hours January 28, 1985. This mode is depicted in figure 1,

which shows that any site along the ground track of the spacecraft is viewed from a number of zenith angles during a single orbital pass. Operation in this manner permits the study of a number of problems of measurement of the radiation field of the Earth. In particular, it provides data for developing a limb-darkening model for a single site over a short period of time rather than by compositing data taken at different times and different locations as is required by the use of most other data sets. The January data were analyzed to produce limb-darkening functions, which have been reported by Smith, Manalo, Suttles, and Walker (1989).

One may expect the limb darkening to change with season due to temperature and humidity changes. The ERBE scanning radiometer aboard the NOAA-9 spacecraft was operated in the along-track scan mode for the period August 3 through 9, 1985, and the scanning radiometer aboard the ERBS spacecraft was operated in the along-track scan mode for August 7 through 14, 1985. The NOAA-9 spacecraft is in a  $99^\circ$  inclination orbit, so that these data provide global coverage. Thus, this data set includes observations over snow and ice. The ERBS data set covers latitudes between  $57^\circ\text{N}$  and  $57^\circ\text{S}$ . Results from the ERBS data can be compared with those from the January along-track operation; therefore, information is provided about seasonal effects on limb-darkening functions.

This paper presents a set of empirical limb-darkening models which were developed from the along-track data of August 1985. The models are

given both in graphical form and in tables. Models are developed for a variety of scene types discriminated by surface type (ocean, land, snow, desert, and coastal) and cloudiness categories (clear, partly cloudy, mostly cloudy, overcast) for day and night. Models are developed separately for the NOAA-9 and for the ERBS data. Intercomparison of the models validates the models and provides a measure of their consistency and accuracy.

## Method

The radiance  $L$  leaving the “top of the atmosphere” is related to the radiant exitance (flux)  $M$  by the limb-darkening function  $R$ :

$$L = \pi^{-1} R M \quad (1)$$

This relation permits one to compute the radiant exitance  $M$  from a measurement of radiance  $L$  in a single direction if the limb-darkening function  $R$  is known. For purposes of data processing, the “top of the atmosphere” is taken to be 30 km above sea level. In this paper, the usual assumption that the outgoing longwave radiation (OLR) is axisymmetric about the vertical is used. The radiant exitance is given in terms of the radiance as

$$M = 2\pi \int_0^{\pi/2} d\theta \sin \theta \cos \theta L \quad (2)$$

where  $\theta$  is the zenith angle of the exiting ray. From these two equations, it follows that  $R$  must satisfy the normalization condition

$$2 \int_0^{\pi/2} d\theta \sin \theta \cos \theta R = 1 \quad (3)$$

As a consequence of this condition, if  $R > 1$  near zenith then  $R < 1$  toward the limb. This is the case except when limb brightening occurs, in which case  $R < 1$  near zenith and  $R > 1$  near the limb. This case is encountered for winter polar conditions, where it is caused by temperature inversion in the air.

Defining  $z = \cos^2 \theta$ , equation (2) can be rewritten as

$$M = \pi \int_0^1 dz L \quad (4)$$

For numerical evaluation of data and to assure that for a Lambertian radiator no quadrature error is incurred for numerical integration, equation (4) is approximated by

$$M = \pi \sum_i \bar{L}_i \Delta z_i \quad (5)$$

where  $\bar{L}_i$  is the average radiance in the  $i$ th angular bin and

$$\Delta z_i = \cos^2 \theta_i - \cos^2 \theta_{i+1}$$

In order to compute limb-darkening functions from along-track data, the radiant exitance  $M$  is computed from the measured radiances  $L$  by use of equation (5). The limb-darkening function  $R(\theta)$  is then computed from equation (1), which gives

$$R(\theta) = \frac{\pi L(\theta)}{M} \quad (6)$$

## Method of Implementation

The procedure for partitioning the orbit track into 108-km-long intervals and allocating measurements to each interval is described by Smith et al. (1989). The scene type of an interval is selected based on the pixels, each of which has its scene type defined by the ERBE scene identification algorithm (Wielicki and Green 1989), with viewing zenith angle of less than  $10^\circ$ . If 80 percent of these pixels agree in scene type, then the interval is assigned that scene and is used in the computation of the limb-darkening functions. Identification of the scene type at nadir view eliminates intervals that have large scene-type variations within them.

The limb-darkening models are computed from equation (6). The radiances are averaged in 18 viewing zenith angle bins of  $5^\circ$  each. Data for the two bins for  $80^\circ$  through  $90^\circ$  are not used due to time response of the sensor and field-of-view contamination by space. The mean radiances for these bins are linearly extrapolated from the centers of the two adjacent bins.

The standard deviation of the radiances within each bin is computed, and if the standard deviation exceeds 1.5 percent of the mean radiance for that bin for ERBS data or 2.0 percent of the mean radiance for each bin for NOAA-9 data, the interval is rejected. A reasonable value of the standard deviation is selected and implemented in order to ensure uniform regions and well-behaved limb-darkening models. Although the 1.5-percent threshold was implemented in the formulation of the January limb-darkening models for ERBS, the standard deviation is increased to 2.0 percent for NOAA-9 because the scanner aboard this spacecraft generated noisier data. If the interval is accepted, the radiant exitance is computed from equation (5), and the limb-darkening function is determined by use of equation (6). The limb-darkening functions are averaged for all intervals for each scene type for each latitude band.

Because of the editing requirement that the standard deviation in any viewing zenith angle be less

than 1.5 and 2.0 percent for ERBS and NOAA-9, respectively, the sampling error for a given interval is a fraction of a percent. From an examination of results, it was found that 5 intervals are sufficient to define the limb-darkening model to a fraction of a percent. For the January results, Smith et al. (1989) used at least 10 intervals for each model.

## Results

Limb-darkening functions have been generated for the ERBE scene identification classes for various latitude zones as listed in tables 1 through 4. The latitude zones, consisting of  $18^\circ$  wide strips starting at the North Pole, are those used for the ERBE inversion calculations. Figure 2 illustrates the local time coverage as a function of latitude for the ERBS and NOAA-9 satellites. Tables 1 and 2 list the number of intervals which were used in the computation of the limb-darkening models for the ERBS for day and night, respectively. No data were taken for zones 1 and 10 since the ERBS is in a  $57^\circ$  inclination orbit and does not make observations poleward of  $57^\circ$  when scanning along track. Thus, the models for latitude zones 2 and 9 are based only upon intervals sampled by ERBS between  $54^\circ$  and  $57^\circ$  and are not representative of the full width of the zone. All scene types are sampled for day and night, with the exception of clear snow. For day and night cases for ERBS, sampling is low for the overcast case.

The NOAA-9 spacecraft provides global coverage. Tables 3 and 4 list the number of intervals that were used in the computation of the NOAA-9 limb-darkening functions. Figure 2 traces the local time coverage of the satellite and shows coverage of latitude zone 1 only during the day and coverage of zone 10 at night only. The present scene identification algorithm is not considered capable of distinguishing between clear snow and overcast over snow scene types. Thus, the snow and overcast over snow scenes may contain mixed measurements of these scene types. This, however, does not cause significant errors due to the similarity of models for these scene types.

The angular sampling for viewing zenith angles  $75^\circ$  to  $80^\circ$  differed for ERBS and NOAA-9. The actual viewing zenith angle in this viewing zenith range is  $75.5^\circ$  for NOAA-9. For NOAA-9, the extrapolation was thus made using  $72.5^\circ$  and  $75.5^\circ$ . It was found that a shift in radiance measurement profile occurs when the ERBS scanner is rotated in azimuth from cross-track to along-track scan mode, which causes the ERBS models to be more limb-darkened than NOAA-9 models. The mean limb-darkening models for ERBS and NOAA-9 are shown in table 5. For viewing zenith angles greater than

$70^\circ$ , the ERBS models are much more limb darkened than the NOAA-9 models. Because of the normalization, limb-darkening models are changed for all viewing zenith angles. In order to compensate for this, an average slope for ERBS and NOAA-9 is computed with the models at viewing zenith angles  $65^\circ$  to  $75^\circ$ . This mean slope is then used to extrapolate the limb-darkening models at viewing zenith angles greater than  $70^\circ$  for each scene type and latitude band. The models are renormalized to produce the results presented here. This slope change for viewing zenith angle greater than  $70^\circ$  was not done for the models presented in NASA RP-1214 (Smith et al. 1989) for January 1985.

The limb-darkening functions for ERBS are shown in figures 3 through 10 for day and figures 11 through 21 for night. These are also tabulated in tables 6 and 7 for numerical reference. The limb-darkening functions for NOAA-9 are shown in figures 22 through 32 for day and figures 33 through 41 for night. These models are presented in tables 8 and 9 for numerical applications.

It is useful to use the zenith value of the limb-darkening function as a measure of limb darkening; increased limb darkening results in the limb-darkening function being increased near zenith due to the normalization condition. For ERBS, the limb-darkening functions for day are in the order of 1.03 to 1.08 at zenith, with 1.06 being typical, whereas the limb-darkening functions for night have values of 1.02 to 1.09 at zenith, with 1.06 being typical. For NOAA-9, the daytime functions range from 1.03 to 1.09 at zenith, with 1.06 being typical. The nighttime limb-darkening functions, with exception of clear snow and overcast scenes at latitudes  $54^\circ\text{S}$  to  $90^\circ\text{S}$  are on the order of 1.02 to 1.06 at zenith, with 1.05 being typical. Limb-darkening functions of 1.00 to 1.02 were computed for clear snow and overcast at zenith for latitudes  $54^\circ\text{S}$  to  $90^\circ\text{S}$ . For viewing zenith angle less than  $70^\circ$ , it is observed that latitude generally causes a variation on the order of 1 percent. This variation is especially evident in different cloud cover categories over land. On the other hand, for viewing zenith angles larger than  $70^\circ$ , variation due to latitude is larger. For operation in the cross-track mode, fluxes are not computed for viewing zenith angles larger than  $70^\circ$  for a variety of reasons. For example, the footprint of the pixel on the Earth is too large.

The limb-darkening function for clear snow and overcast scenes for NOAA-9 for night differs from all the other functions for the different scenes. All the intervals that were used for the computation of these models are located in zones 9 and 10, the last two latitude zones in the Southern Hemisphere. All

the intervals that were used for the computation of the overcast models in this region have been identified to be over geographical-type snow. The limb brightening exists in this region probably because of nighttime temperature inversion in the air near the ground. Again, difficulty in discriminating between snow and overcast over snow may have led to mixed measurements between the two scenes. The limb-darkening functions for snow during the day for NOAA-9, sampled at zones 1 and 2, did not show the limb-brightening phenomenon.

For individual scene types, it is seen that the limb-darkening functions for clear, partly cloudy, and overcast over geographical-type ocean have about 1 percent more limb darkening than NOAA-9 models for both day and night. On the other hand, the daytime clear and partly cloudy over land models in the Northern Hemisphere for NOAA-9 are about 2 percent higher than their ERBS counterparts. The opposite is true for clear and partly cloudy over land at night. Coverage of identical scene types at comparable latitude zones but differing local times may contribute to these model differences between the satellites. For the remaining scenes, with the exception of overcast, the limb-darkening models for the ERBS are generally about 1 percent more limb darkened than the corresponding NOAA-9 models.

Because the limb-darkening functions are similar for the different cases, a mean function was formed for the day and one for the night for both satellites by averaging over all scene types and latitude zones without weighting by population. These mean functions are tabulated in table 10 and shown in figure 42. The ERBS mean limb-darkening models have 0.5 percent more limb darkening than the NOAA-9 mean models. For both spacecraft, the difference between the day and night mean models is on the order of 0.5 percent. The mean models for both satellites equal 1.0 at around  $55^\circ$ , as do most of the individual cases. For viewing zenith angle larger than  $70^\circ$ , the ERBS and NOAA-9 limb-darkening functions differ by about 1.5 percent.

A comparison of the limb-darkening models for January 1985 presented by Smith et al. (1989) and the August models indicate that any seasonal effects must be 0.5 percent or less near zenith. For the

typical model, local time causes a 1.0-percent effect near zenith.

Latitudinal effects on the limb-darkening functions are also suggested when considering seasonal changes at or near the polar regions. From the January ERBS data set, the limb-darkening functions presented for clear snow for  $36^\circ\text{N}$  to  $57^\circ\text{N}$  did not exhibit limb brightening. However, the limb-brightening phenomenon was present for the clear snow models determined from intervals sampled at the South Pole by NOAA-9.

## Conclusions

Limb-darkening models have been developed by use of along-track scanning data from a scanning radiometer aboard the ERBS and NOAA-9 spacecraft during August 1985. With this special set of data, it is possible to classify cloudiness of an interval at near nadir in order to eliminate intervals with large scene type variations. The NOAA-9 spacecraft allows for global coverage which provides data for the polar regions, whereas the ERBS spacecraft covers the latitudinal regions between  $57^\circ\text{N}$  and  $57^\circ\text{S}$ . The limb-darkening models derived from the ERBS spacecraft are about 1 percent higher at zenith than those generated from the NOAA-9 satellite. The typical value of the limb-darkening model at zenith for ERBS is 1.06 during the day and night, whereas the typical model value for day is 1.06 and 1.05 at night for NOAA-9. The latitude causes a variation on the order of 1 percent for viewing zenith angles less than  $70^\circ$ . A comparison of the ERBS limb-darkening functions derived from scanner along-track operation in January 1985 (NASA Reference Publication 1214) with the August 1985 limb-darkening functions show close agreement between the two sets of models. However, the clear snow limb-darkening models for August 1985 showed limb brightening at the South Pole, whereas January 1985 clear snow models did not exhibit limb brightening.

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Table 1. Number of Intervals Used To Develop Limb-Darkening Models for Day for ERBS

Scene ID (a)	Number of intervals in latitude range, deg, of							
	72N-54N (zone 2)	54N-36N (zone 3)	36N-18N (zone 4)	18N-0 (zone 5)	0-18S (zone 6)	18S-36S (zone 7)	36S-54S (zone 8)	54S-72S (zone 9)
Clear ocean	2	40	135	73	163	174	37	2
Clear land	52	97	14	0	68	64	4	0
Clear snow	0	0	0	0	0	0	0	0
Clear desert	0	0	4	0	0	0	0	0
Clear land-ocean	0	13	8	0	0	2	0	0
PC/ocean	0	53	91	96	117	127	155	10
PC/land	27	105	38	19	10	7	0	0
PC/land-ocean	0	4	4	2	3	0	2	0
MC/ocean	3	107	69	12	70	85	104	48
MC/land	6	11	2	0	0	6	0	0
MC/land-ocean	0	0	0	0	0	2	0	0
Overcast	2	4	0	2	0	3	4	7

<sup>a</sup>MC, mostly cloudy; PC, partly cloudy.

Table 2. Number of Intervals Used To Develop Limb-Darkening Models for Night for ERBS

Scene ID (a)	Number of intervals in latitude range, deg, of							
	72N-54N (zone 2)	54N-36N (zone 3)	36N-18N (zone 4)	18N-0 (zone 5)	0-18S (zone 6)	18S-36S (zone 7)	36S-54S (zone 8)	54S-72S (zone 9)
Clear ocean	8	58	116	46	111	75	15	0
Clear land	14	40	5	2	96	45	0	0
Clear snow	0	0	0	0	0	0	0	0
Clear desert	0	0	100	0	0	5	0	0
Clear land-ocean	0	13	5	0	0	4	0	0
PC/ocean	3	102	314	144	319	375	190	12
PC/land	95	194	29	9	11	37	0	0
PC/land-ocean	2	7	0	0	0	0	0	0
MC/ocean	115	156	14	18	27	42	213	158
MC/land	29	9	4	0	0	7	4	0
MC/land-ocean	5	3	0	0	0	0	0	0
Overcast	3	0	2	0	0	0	5	13

<sup>a</sup>MC, mostly cloudy; PC, partly cloudy.

Table 3. Number of Intervals Used To Develop Limb-Darkening Models for Day for NOAA-9

Scene ID (a)	Number of intervals in latitude range, deg, of--									
	90N-72N (zone 1)	72N-54N (zone 2)	54N-36N (zone 3)	36N-18N (zone 4)	18N-0 (zone 5)	0-18S (zone 6)	18S-36S (zone 7)	36S-54S (zone 8)	54S-72S (zone 9)	72S-90S (zone 10)
Clear ocean	0	4	43	40	26	98	88	12	0	0
Clear land	3	18	21	2	0	50	54	0	0	0
Clear snow	30	14	0	0	0	0	0	0	0	0
Clear desert	0	0	2	70	0	0	14	0	0	0
Clear land-ocean	0	0	0	2	0	5	0	0	0	0
PC/ocean	0	3	31	126	128	218	261	138	0	0
PC/land	2	78	64	18	14	36	13	3	0	0
PC/land-ocean	0	0	0	0	0	0	0	0	0	0
MC/ocean	156	46	60	21	11	77	55	94	3	0
MC/land	2	42	9	0	2	6	3	0	0	0
MC/land-ocean	5	4	0	0	0	0	0	0	0	0
Overcast	60	20	10	0	5	0	2	3	2	0

<sup>a</sup>MC, mostly cloudy; PC, partly cloudy.

Table 4. Number of Intervals Used To Develop Limb-Darkening Models for Night for NOAA-9

Scene ID (a)	Number of intervals in latitude range, deg, of									
	90N-72N (zone 1)	72N-54N (zone 2)	54N-36N (zone 3)	36N-18N (zone 4)	18N-0 (zone 5)	0-18S (zone 6)	18S-36S (zone 7)	36S-54S (zone 8)	54S-72S (zone 9)	72S-90S (zone 10)
Clear ocean	0	0	13	23	13	47	16	14	0	0
Clear land	0	6	10	0	0	47	16	0	0	0
Clear snow	0	0	0	0	0	0	0	0	20	35
Clear desert	0	0	6	105	4	0	10	0	0	0
Clear land-ocean	0	0	0	4	0	0	0	0	0	0
PC/ocean	0	0	9	174	185	401	306	66	0	0
PC/land	0	27	34	20	0	88	54	0	0	0
PC/land-ocean	0	0	2	0	0	0	0	0	0	0
MC/ocean	0	0	2	17	36	103	72	31	30	0
MC/land	0	0	0	0	0	5	0	0	0	0
MC/land-ocean	0	0	0	0	0	0	0	0	2	0
Overcast	0	0	0	0	3	0	0	5	170	72

<sup>a</sup>MC, mostly cloudy; PC, partly cloudy.

Table 5. Preliminary Mean Limb-Darkening Models for August 1985

Viewing zenith angle range, deg	Average limb-darkening models for---			
	ERBS		NOAA-9	
	Day	Night	Day	Night
0-5	1.060	1.057	1.056	1.046
5-10	1.059	1.055	1.055	1.046
10-15	1.057	1.053	1.054	1.046
15-20	1.055	1.052	1.053	1.044
20-25	1.054	1.049	1.049	1.042
25-30	1.049	1.046	1.046	1.039
30-35	1.043	1.041	1.042	1.035
35-40	1.036	1.034	1.035	1.030
40-45	1.028	1.027	1.026	1.023
45-50	1.019	1.018	1.016	1.014
50-55	1.006	1.008	1.000	1.000
55-60	0.991	0.993	0.981	0.986
60-65	0.970	0.973	0.961	0.969
65-70	0.944	0.948	0.941	0.951
70-75	0.906	0.913	0.911	0.924
75-80	0.844	0.852	0.874	0.890
80-85	0.783	0.791	0.828	0.844
85-90	0.721	0.731	0.783	0.801

Table 6. Limb-Darkening Models for Day for ERBS

Scene ID (a)	Limb-darkening model for																		
	Viewing zenith angle range, deg, of																		
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	
Latitude: 72°N 54°N																			
Clear ocean	1.056	1.053	1.051	1.050	1.050	1.046	1.039	1.032	1.023	1.010	.993	.986	.969	.946	.912	.878	.844	.810	
Clean land	1.051	1.050	1.048	1.047	1.046	1.042	1.036	1.029	1.022	1.014	1.002	.989	.970	.948	.914	.880	.846	.812	
PC/land	1.048	1.047	1.046	1.044	1.043	1.040	1.034	1.028	1.022	1.014	1.004	.990	.973	.950	.916	.882	.848	.814	
MC/ocean	1.054	1.050	1.047	1.046	1.044	1.039	1.035	1.027	1.021	1.020	1.004	.990	.967	.947	.913	.879	.845	.811	
MC/land	1.054	1.051	1.049	1.046	1.044	1.041	1.034	1.027	1.021	1.013	1.003	.990	.972	.950	.916	.882	.848	.813	
Overcast	1.032	1.033	1.035	1.032	1.033	1.034	1.030	1.024	1.019	1.018	1.011	.995	.972	.961	.927	.893	.858	.824	
Latitude: 54°N 36°N																			
Clear ocean	1.056	1.056	1.054	1.052	1.050	1.046	1.040	1.032	1.023	1.015	1.002	.987	.966	.938	.904	.870	.836	.803	
Clear land	1.053	1.052	1.050	1.049	1.047	1.043	1.037	1.030	1.023	1.014	1.003	.989	.970	.943	.909	.875	.841	.808	
Clear land-ocean	1.051	1.050	1.048	1.047	1.046	1.041	1.035	1.029	1.022	1.014	1.003	.990	.970	.946	.912	.879	.845	.811	
PC/ocean	1.054	1.052	1.051	1.049	1.048	1.043	1.037	1.030	1.022	1.014	1.002	.988	.969	.943	.910	.876	.842	.808	
PC/land	1.056	1.055	1.053	1.052	1.050	1.045	1.039	1.032	1.024	1.014	1.002	.988	.967	.940	.906	.872	.839	.805	
PC/land-ocean	1.054	1.054	1.051	1.050	1.047	1.043	1.037	1.031	1.021	1.014	1.002	.989	.971	.944	.910	.876	.842	.808	
MC/ocean	1.048	1.047	1.046	1.044	1.044	1.040	1.034	1.028	1.021	1.014	1.003	.991	.973	.949	.915	.882	.848	.814	
MC/land	1.044	1.044	1.043	1.042	1.041	1.036	1.031	1.026	1.020	1.014	1.004	.992	.976	.955	.921	.887	.853	.819	
Overcast	1.034	1.034	1.033	1.032	1.032	1.030	1.026	1.022	1.020	1.015	1.007	.996	.982	.966	.932	.898	.864	.830	
Latitude: 36°N 18°N																			
Clear ocean	1.060	1.059	1.057	1.055	1.053	1.048	1.042	1.034	1.025	1.015	1.001	.986	.963	.934	.900	.867	.833	.799	
Clear land	1.064	1.063	1.061	1.058	1.056	1.051	1.043	1.035	1.027	1.015	1.001	.983	.959	.930	.896	.863	.829	.795	
Clear desert	1.059	1.058	1.057	1.054	1.053	1.047	1.040	1.033	1.024	1.015	1.001	.985	.964	.938	.904	.870	.836	.802	
Clear land-ocean	1.055	1.054	1.052	1.051	1.049	1.045	1.039	1.033	1.025	1.017	1.004	.988	.967	.937	.903	.870	.836	.802	
PC/ocean	1.062	1.061	1.059	1.057	1.055	1.050	1.043	1.035	1.025	1.015	1.001	.985	.962	.932	.898	.865	.831	.797	
PC/land	1.065	1.064	1.063	1.061	1.058	1.053	1.046	1.037	1.027	1.015	1.001	.984	.958	.926	.892	.859	.825	.791	
PC/ocean-land	1.064	1.064	1.060	1.059	1.057	1.051	1.044	1.035	1.025	1.014	1.000	.985	.961	.929	.895	.862	.828	.794	
MC/ocean	1.050	1.050	1.048	1.047	1.045	1.041	1.036	1.029	1.022	1.014	1.033	.990	.972	.947	.913	.879	.846	.812	
MC/land	1.074	1.073	1.071	1.070	1.067	1.057	1.048	1.042	1.032	1.016	.997	.980	.951	.916	.882	.848	.814	.781	
Latitude: 18°N 0°																			
Clear ocean	1.064	1.062	1.060	1.058	1.056	1.051	1.044	1.036	1.026	1.016	1.001	.984	.960	.929	.896	.862	.828	.794	
PC/ocean	1.063	1.062	1.060	1.057	1.055	1.050	1.044	1.035	1.026	1.015	1.000	.984	.961	.931	.897	.863	.829	.796	
PC/land	1.077	1.076	1.073	1.070	1.067	1.061	1.051	1.041	1.029	1.016	.998	.978	.949	.914	.881	.847	.813	.779	
PC/land-ocean	1.078	1.078	1.075	1.073	1.070	1.062	1.055	1.042	1.031	1.014	.996	.975	.946	.913	.880	.846	.812	.778	
MC/ocean	1.051	1.051	1.049	1.048	1.047	1.043	1.036	1.031	1.023	1.014	1.003	.989	.969	.944	.910	.876	.842	.809	
Overcast	1.057	1.056	1.055	1.052	1.049	1.044	1.037	1.030	1.023	1.015	1.002	.989	.968	.939	.905	.871	.837	.803	
Latitude: 0° 18°S																			
Clear ocean	1.057	1.056	1.055	1.053	1.051	1.047	1.041	1.034	1.025	1.016	1.003	.986	.964	.935	.901	.868	.834	.800	
Clear land	1.070	1.068	1.066	1.063	1.060	1.054	1.046	1.038	1.028	1.016	1.000	.981	.956	.923	.889	.856	.822	.788	
PC/ocean	1.058	1.058	1.056	1.054	1.052	1.047	1.041	1.034	1.025	1.016	1.002	.986	.964	.935	.901	.868	.834	.800	
PC/land	1.063	1.062	1.061	1.058	1.057	1.052	1.045	1.036	1.028	1.016	1.002	.983	.958	.927	.893	.859	.826	.792	
PC/land-ocean	1.077	1.076	1.073	1.072	1.068	1.060	1.052	1.041	1.031	1.016	.998	.976	.948	.913	.880	.846	.812	.779	
MC/ocean	1.051	1.050	1.048	1.047	1.046	1.042	1.036	1.029	1.022	1.014	1.001	.989	.971	.946	.912	.878	.844	.811	

<sup>a</sup>MC, mostly cloudy; PC, partly cloudy.

Table 6. Concluded

Scene ID (a)	Limb-darkening model for																	
	Viewing zenith angle range, deg, of																	
	0 5	5 10	10 15	15 20	20 25	25 30	30 35	35 40	40 45	45 50	50 55	55 60	60-65	65 70	70 75	75 80	80 85	85 90
Latitude: 18°S 36°S																		
Clear ocean	1.056	1.055	1.054	1.052	1.050	1.046	1.040	1.033	1.024	1.016	1.002	.986	.966	.937	.903	.869	.836	.802
Clear land	1.065	1.065	1.063	1.060	1.058	1.052	1.045	1.036	1.027	1.016	1.000	.982	.958	.927	.893	.859	.826	.792
Clear land-ocean	1.061	1.060	1.060	1.059	1.056	1.052	1.044	1.034	1.028	1.016	1.002	.982	.959	.929	.896	.862	.828	.794
PC/ocean	1.056	1.055	1.053	1.051	1.050	1.045	1.039	1.032	1.024	1.016	1.002	.986	.967	.939	.906	.872	.838	.804
PC/land	1.056	1.056	1.053	1.052	1.050	1.046	1.040	1.032	1.023	1.015	1.002	.987	.965	.938	.905	.871	.837	.803
MC/ocean	1.046	1.046	1.044	1.043	1.042	1.038	1.034	1.028	1.021	1.014	1.003	.991	.975	.952	.918	.884	.850	.817
MC/land	1.040	1.039	1.038	1.036	1.036	1.034	1.029	1.025	1.019	1.014	1.005	.995	.979	.960	.926	.892	.859	.825
MC/land-ocean	1.031	1.032	1.029	1.028	1.029	1.027	1.026	1.021	1.018	1.016	1.010	.999	.998	.963	.930	.896	.862	.828
Overcast	1.035	1.036	1.035	1.033	1.032	1.030	1.028	1.024	1.020	1.013	1.003	.994	.980	.966	.932	.899	.865	.831
Latitude: 36°S 54°S																		
Clear ocean	1.057	1.057	1.055	1.053	1.052	1.047	1.042	1.034	1.026	1.017	1.002	.986	.964	.933	.899	.865	.832	.798
Clear land	1.060	1.059	1.057	1.056	1.053	1.049	1.042	1.034	1.026	1.017	1.002	.985	.959	.933	.899	.865	.831	.797
PC/ocean	1.056	1.056	1.054	1.052	1.050	1.046	1.039	1.032	1.024	1.015	1.002	.986	.966	.938	.904	.870	.837	.803
PC/land-ocean	1.064	1.064	1.062	1.059	1.056	1.050	1.043	1.035	1.025	1.014	1.000	.985	.964	.929	.895	.862	.828	.794
MC/ocean	1.048	1.047	1.046	1.045	1.044	1.039	1.034	1.028	1.021	1.014	1.002	.989	.973	.950	.916	.882	.848	.815
Overcast	1.038	1.039	1.037	1.036	1.037	1.034	1.030	1.025	1.020	1.012	1.002	.993	.981	.961	.927	.893	.859	.826
Latitude: 54°S 72°S																		
Clear ocean	1.055	1.056	1.056	1.054	1.053	1.048	1.041	1.033	1.024	1.014	1.001	.985	.959	.938	.905	.871	.838	.804
PC/ocean	1.059	1.057	1.055	1.053	1.052	1.048	1.042	1.033	1.024	1.015	.999	.982	.961	.939	.905	.872	.838	.804
MC/ocean	1.051	1.050	1.048	1.047	1.046	1.042	1.037	1.029	1.022	1.015	1.002	.987	.969	.946	.913	.879	.845	.811
Overcast	1.049	1.048	1.045	1.045	1.045	1.040	1.035	1.026	1.019	1.013	1.000	.986	.968	.956	.922	.888	.855	.821

<sup>a</sup>MC, mostly cloudy; PC, partly cloudy.

Table 7. Limb-Darkening Models for Night for ERBS

Scene ID (a)	Limb-darkening model for																		
	Viewing zenith angle range, deg. of																		
	0 5	5 10	10 15	15 20	20 25	25 30	30 35	35 40	40 45	45 50	50 55	55 60	60 65	65 70	70 75	75 80	80 85	85 90	
Latitude: 72°N 54°N																			
Clear ocean	1.058	1.057	1.056	1.054	1.052	1.048	1.044	1.037	1.032	1.024	1.012	.996	.979	.951	.915	.856	.797	.738	
Clean land	1.048	1.047	1.046	1.045	1.042	1.039	1.034	1.028	1.022	1.014	1.005	.991	.974	.951	.920	.880	.840	.800	
PC/ocean	1.060	1.057	1.055	1.054	1.051	1.048	1.045	1.037	1.029	1.020	1.011	.996	.978	.954	.918	.874	.829	.785	
PC/land	1.045	1.043	1.042	1.041	1.039	1.036	1.032	1.026	1.021	1.014	1.006	.994	.979	.958	.931	.888	.844	.801	
PC/land-ocean	1.056	1.055	1.052	1.050	1.048	1.045	1.040	1.032	1.025	1.017	1.005	.992	.973	.947	.911	.855	.799	.744	
MC/ocean	1.048	1.047	1.045	1.044	1.042	1.039	1.035	1.029	1.023	1.016	1.007	.994	.978	.956	.927	.883	.839	.795	
MC/land	1.042	1.040	1.038	1.038	1.036	1.033	1.029	1.023	1.019	1.012	1.005	.994	.981	.961	.935	.891	.846	.802	
MC/land-ocean	1.049	1.046	1.044	1.042	1.041	1.037	1.033	1.027	1.021	1.013	1.004	.990	.973	.952	.925	.887	.849	.811	
Overcast	1.017	1.016	1.017	1.016	1.014	1.014	1.011	1.008	1.004	.999	.999	.990	.983	.979	.979	.982	.985	.988	
Latitude: 54°N 36°N																			
Clear ocean	1.064	1.062	1.060	1.059	1.056	1.052	1.046	1.039	1.031	1.021	1.009	.992	.969	.939	.900	.831	.763	.695	
Clear land	1.058	1.056	1.054	1.053	1.051	1.047	1.041	1.034	1.028	1.019	1.008	.993	.973	.947	.911	.839	.767	.695	
Clear land-ocean	1.060	1.059	1.057	1.056	1.052	1.048	1.043	1.037	1.029	1.019	1.007	.991	.970	.942	.905	.837	.769	.701	
PC/ocean	1.063	1.062	1.059	1.058	1.055	1.051	1.046	1.038	1.031	1.021	1.008	.991	.970	.940	.901	.838	.775	.712	
PC/land	1.057	1.055	1.054	1.053	1.050	1.047	1.042	1.035	1.029	1.020	1.009	.994	.975	.948	.911	.844	.778	.711	
PC/land-ocean	1.059	1.057	1.057	1.056	1.054	1.050	1.046	1.039	1.032	1.023	1.011	.997	.979	.952	.913	.855	.798	.740	
MC/ocean	1.058	1.056	1.054	1.053	1.051	1.047	1.042	1.036	1.029	1.020	1.009	.994	.974	.947	.911	.845	.780	.714	
MC/land	1.049	1.048	1.045	1.045	1.044	1.041	1.035	1.031	1.024	1.017	1.007	.995	.977	.953	.921	.861	.801	.741	
MC/land-ocean	1.061	1.060	1.058	1.056	1.053	1.050	1.046	1.037	1.031	1.019	1.009	.991	.967	.938	.903	.835	.768	.700	
Latitude: 36°N 18°N																			
Clear ocean	1.068	1.066	1.064	1.063	1.060	1.055	1.050	1.041	1.033	1.023	1.009	.991	.969	.939	.899	.834	.768	.703	
Clear land	1.061	1.060	1.058	1.056	1.053	1.049	1.044	1.037	1.029	1.019	1.007	.988	.968	.941	.900	.840	.780	.719	
Clear desert	1.059	1.058	1.056	1.055	1.051	1.047	1.042	1.035	1.028	1.019	1.008	.992	.973	.946	.909	.841	.772	.704	
Clear land-ocean	1.062	1.059	1.058	1.057	1.053	1.049	1.044	1.037	1.030	1.020	1.008	.990	.970	.940	.900	.835	.771	.707	
PC/ocean	1.067	1.065	1.063	1.062	1.058	1.054	1.048	1.040	1.032	1.021	1.008	.990	.968	.938	.898	.833	.768	.703	
PC/land	1.070	1.068	1.067	1.065	1.061	1.057	1.051	1.043	1.035	1.024	1.011	.991	.968	.936	.895	.823	.752	.680	
MC/ocean	1.055	1.054	1.052	1.051	1.048	1.044	1.039	1.033	1.026	1.017	1.008	.992	.975	.950	.915	.847	.780	.712	
MC/land	1.049	1.048	1.047	1.047	1.044	1.042	1.037	1.032	1.026	1.020	1.010	.995	.977	.952	.915	.851	.786	.721	
Overcast	1.038	1.037	1.038	1.035	1.033	1.033	1.029	1.021	1.018	1.009	1.001	.992	.974	.963	.945	.907	.869	.832	
Latitude: 18°N 0°																			
Clear ocean	1.067	1.065	1.063	1.062	1.058	1.054	1.047	1.039	1.031	1.020	1.007	.989	.967	.937	.897	.828	.758	.689	
Clear land	1.090	1.088	1.087	1.084	1.079	1.073	1.065	1.055	1.046	1.031	1.013	.994	.964	.924	.877	.812	.748	.683	
PC/ocean	1.071	1.070	1.067	1.066	1.062	1.057	1.051	1.042	1.034	1.022	1.008	.990	.965	.933	.890	.821	.752	.684	
PC/land	1.079	1.076	1.076	1.073	1.069	1.064	1.057	1.048	1.038	1.026	1.011	.991	.963	.927	.879	.796	.714	.631	
MC/ocean	1.055	1.054	1.053	1.052	1.049	1.046	1.041	1.035	1.029	1.020	1.009	.995	.976	.952	.919	.852	.784	.716	
Latitude: 0° 18°S																			
Clear ocean	1.064	1.062	1.060	1.059	1.056	1.052	1.046	1.039	1.031	1.021	1.009	.992	.970	.940	.901	.828	.755	.683	
Clear land	1.059	1.058	1.056	1.055	1.052	1.048	1.042	1.035	1.029	1.020	1.010	.995	.973	.947	.909	.839	.770	.700	
PC/ocean	1.063	1.061	1.059	1.058	1.055	1.051	1.045	1.037	1.030	1.020	1.008	.992	.970	.942	.902	.833	.765	.696	
PC/land	1.062	1.061	1.059	1.059	1.055	1.052	1.047	1.040	1.033	1.023	1.012	.996	.971	.936	.890	.817	.743	.670	
MC/ocean	1.056	1.055	1.053	1.052	1.050	1.045	1.041	1.034	1.027	1.018	1.007	.991	.972	.945	.909	.849	.789	.729	

<sup>a</sup>MC, mostly cloudy; PC, partly cloudy.

Table 7. Concluded

Scene ID (a)	Limb-darkening model for																	
	Viewing zenith angle range, deg, of																	
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90
Latitude: 18°S-36°S																		
Clear ocean	1.062	1.060	1.058	1.057	1.054	1.050	1.045	1.037	1.030	1.021	1.009	.994	.972	.945	.907	.836	.766	.695
Clear land	1.050	1.048	1.047	1.046	1.044	1.041	1.036	1.031	1.025	1.018	1.010	.998	.980	.957	.923	.847	.771	.696
Clear desert	1.043	1.043	1.042	1.040	1.038	1.035	1.030	1.024	1.019	1.013	1.005	.995	.977	.956	.924	.889	.853	.817
Clear land-ocean	1.061	1.059	1.057	1.056	1.053	1.048	1.042	1.035	1.028	1.019	1.008	.992	.972	.947	.910	.834	.758	.682
PC/ocean	1.060	1.058	1.057	1.056	1.053	1.049	1.044	1.037	1.030	1.020	1.009	.993	.973	.945	.907	.833	.758	.684
PC/land	1.051	1.050	1.048	1.047	1.045	1.042	1.037	1.031	1.025	1.018	1.009	.996	.979	.958	.925	.852	.780	.707
MC/ocean	1.052	1.051	1.049	1.048	1.046	1.042	1.038	1.031	1.026	1.018	1.009	.997	.979	.957	.925	.851	.778	.704
MC/land	1.052	1.050	1.049	1.048	1.045	1.042	1.038	1.033	1.027	1.018	1.009	.996	.978	.957	.926	.842	.758	.674
Latitude: 36°S-54°S																		
Clear ocean	1.063	1.062	1.060	1.059	1.056	1.052	1.047	1.039	1.032	1.022	1.009	.991	.968	.935	.890	.826	.762	.697
PC/land	1.062	1.060	1.058	1.057	1.054	1.050	1.045	1.038	1.031	1.021	1.010	.993	.971	.942	.902	.833	.763	.693
MC/ocean	1.055	1.053	1.051	1.050	1.048	1.044	1.039	1.032	1.026	1.018	1.008	.993	.973	.949	.915	.860	.804	.748
MC/land	1.048	1.046	1.044	1.045	1.042	1.039	1.035	1.030	1.025	1.018	1.009	.998	.982	.958	.924	.852	.781	.709
Overcast	1.048	1.045	1.044	1.043	1.041	1.037	1.033	1.026	1.021	1.011	1.004	.993	.976	.957	.931	.880	.830	.779
Latitude: 54°S-72°S																		
PC/ocean	1.052	1.050	1.049	1.049	1.046	1.042	1.037	1.030	1.024	1.015	1.005	.992	.972	.947	.916	.867	.817	.768
MC/ocean	1.050	1.048	1.046	1.046	1.043	1.040	1.035	1.029	1.023	1.015	1.006	.993	.975	.953	.921	.875	.829	.782
Overcast	1.040	1.037	1.036	1.037	1.035	1.032	1.028	1.021	1.018	1.010	1.004	.995	.981	.963	.940	.910	.881	.852

<sup>a</sup>MC, mostly cloudy; PC, partly cloudy.



Table 8. Limb-Darkening Models for Day for NOAA-9

Scene ID (a)	Limb-darkening model for																	
	Viewing zenith angle range, deg. of																	
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90
Latitude: 90°N 72°N																		
Clear land	1.056	1.055	1.054	1.053	1.050	1.047	1.043	1.037	1.029	1.019	1.004	.983	.959	.935	.901	.867	.833	.799
Clear snow	1.025	1.024	1.025	1.025	1.023	1.022	1.021	1.018	1.015	1.011	1.004	.995	.988	.985	.951	.916	.882	.848
PC/land	1.061	1.060	1.058	1.056	1.053	1.048	1.042	1.034	1.026	1.015	.999	.978	.958	.938	.904	.871	.837	.808
MC/ocean	1.040	1.039	1.039	1.038	1.036	1.033	1.031	1.026	1.021	1.013	1.002	.988	.974	.963	.929	.895	.861	.827
MC/land	1.055	1.055	1.054	1.051	1.047	1.042	1.038	1.031	1.021	1.010	.994	.978	.965	.955	.921	.887	.853	.819
MC/land-ocean	1.041	1.042	1.041	1.040	1.037	1.034	1.032	1.028	1.022	1.014	1.003	.988	.972	.957	.923	.889	.855	.821
Overcast	1.035	1.035	1.035	1.034	1.032	1.029	1.027	1.023	1.018	1.011	1.001	.989	.979	.973	.939	.905	.870	.836
Latitude: 72°N 54°N																		
Clear ocean	1.039	1.039	1.038	1.037	1.036	1.035	1.034	1.031	1.026	1.018	1.006	.990	.973	.951	.917	.883	.849	.815
Clear land	1.068	1.067	1.066	1.064	1.059	1.054	1.048	1.040	1.030	1.017	1.000	.979	.952	.922	.889	.855	.821	.787
Clear snow	1.039	1.038	1.038	1.037	1.036	1.033	1.031	1.026	1.020	1.013	1.001	.989	.977	.965	.931	.897	.863	.829
PC/ocean	1.059	1.058	1.058	1.057	1.054	1.050	1.046	1.040	1.032	1.021	1.005	.981	.953	.925	.891	.857	.823	.789
PC/land	1.059	1.058	1.058	1.056	1.053	1.049	1.044	1.037	1.028	1.016	1.000	.980	.958	.936	.902	.868	.834	.800
MC/ocean	1.046	1.045	1.045	1.044	1.041	1.037	1.034	1.029	1.023	1.014	1.002	.987	.970	.954	.920	.886	.852	.818
MC/land	1.049	1.048	1.048	1.047	1.044	1.041	1.038	1.031	1.023	1.013	.999	.982	.966	.951	.917	.883	.849	.815
MC/land-ocean	1.040	1.040	1.040	1.038	1.035	1.034	1.031	1.026	1.020	1.012	1.001	.987	.975	.964	.930	.896	.862	.828
Overcast	1.038	1.037	1.037	1.036	1.034	1.031	1.029	1.024	1.019	1.011	1.001	.988	.977	.968	.934	.900	.866	.832
Latitude: 54°N 36°N																		
Clear ocean	1.056	1.055	1.055	1.054	1.051	1.048	1.044	1.038	1.030	1.020	1.005	.984	.958	.929	.895	.861	.828	.794
Clear land	1.081	1.080	1.078	1.074	1.070	1.063	1.056	1.047	1.034	1.019	1.000	.973	.940	.905	.871	.837	.803	.770
Clear desert	1.074	1.074	1.071	1.067	1.062	1.056	1.050	1.041	1.030	1.016	.998	.975	.948	.921	.887	.853	.819	.785
PC/ocean	1.056	1.055	1.055	1.053	1.050	1.046	1.042	1.036	1.027	1.017	1.003	.984	.962	.936	.902	.868	.834	.800
PC/land	1.064	1.063	1.062	1.060	1.056	1.051	1.046	1.038	1.029	1.017	1.001	.979	.954	.929	.895	.861	.827	.793
MC/ocean	1.047	1.047	1.047	1.046	1.043	1.040	1.036	1.030	1.024	1.015	1.002	.986	.967	.948	.914	.880	.846	.813
MC/land	1.045	1.044	1.044	1.043	1.040	1.037	1.034	1.028	1.021	1.012	.999	.985	.971	.959	.925	.891	.857	.823
Overcast	1.035	1.036	1.037	1.037	1.034	1.031	1.028	1.024	1.018	1.011	1.003	.991	.979	.967	.933	.899	.865	.831
Latitude: 36°N 18°N																		
Clear ocean	1.055	1.055	1.054	1.053	1.050	1.047	1.043	1.037	1.028	1.017	1.002	.983	.961	.935	.901	.867	.833	.800
Clear land	1.087	1.086	1.084	1.080	1.075	1.068	1.060	1.049	1.038	1.022	1.000	.970	.936	.894	.861	.827	.793	.759
Clear desert	1.071	1.070	1.068	1.065	1.061	1.055	1.049	1.040	1.029	1.015	.997	.975	.949	.924	.891	.857	.823	.789
Clear land-ocean	1.042	1.041	1.041	1.039	1.038	1.036	1.034	1.030	1.023	1.013	1.002	.989	.973	.958	.924	.890	.856	.822
PC/ocean	1.056	1.056	1.055	1.054	1.051	1.047	1.043	1.036	1.027	1.016	1.001	.981	.959	.936	.902	.868	.834	.800
PC/land	1.081	1.080	1.079	1.075	1.070	1.063	1.056	1.046	1.033	1.017	.996	.970	.940	.912	.878	.844	.810	.776
MC/ocean	1.044	1.043	1.043	1.042	1.039	1.037	1.034	1.029	1.023	1.014	1.002	.988	.973	.956	.922	.888	.854	.820
Latitude: 18°N 0°																		
Clear ocean	1.060	1.059	1.058	1.057	1.054	1.050	1.045	1.038	1.028	1.017	1.000	.980	.957	.931	.897	.863	.829	.795
PC/ocean	1.060	1.060	1.059	1.057	1.054	1.050	1.045	1.038	1.029	1.018	1.002	.981	.957	.929	.895	.861	.827	.793
PC/land	1.083	1.082	1.080	1.077	1.071	1.065	1.058	1.047	1.033	1.016	.993	.966	.938	.911	.877	.843	.810	.776
MC/ocean	1.060	1.059	1.058	1.057	1.053	1.049	1.044	1.035	1.025	1.013	.996	.977	.957	.939	.905	.871	.837	.803
MC/land	1.062	1.060	1.058	1.057	1.053	1.048	1.043	1.035	1.024	1.011	.992	.974	.959	.946	.912	.878	.844	.810
Overcast	1.044	1.045	1.046	1.046	1.044	1.042	1.040	1.034	1.027	1.018	1.033	.985	.965	.945	.911	.877	.843	.809

<sup>a</sup>MC, mostly cloudy; PC, partly cloudy.

Table 8. Concluded

Scene ID (a)	Limb-darkening model for																	
	Viewing zenith angle range, deg, of -																	
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90
Latitude: 0°-18°S																		
Clear ocean	1.056	1.056	1.055	1.053	1.050	1.046	1.042	1.036	1.027	1.016	1.000	.981	.960	.937	.904	.870	.836	.802
Clear land	1.068	1.067	1.066	1.063	1.059	1.054	1.048	1.040	1.031	1.018	1.000	.978	.952	.923	.889	.856	.822	.788
Clear land-ocean	1.054	1.053	1.053	1.051	1.047	1.043	1.039	1.033	1.025	1.015	1.000	.983	.965	.945	.911	.877	.843	.809
PC/ocean	1.057	1.056	1.055	1.054	1.050	1.046	1.042	1.035	1.027	1.016	1.000	.980	.960	.938	.904	.870	.836	.802
PC/land	1.058	1.058	1.058	1.056	1.053	1.049	1.044	1.037	1.029	1.017	1.000	.980	.958	.935	.901	.867	.833	.799
MC/ocean	1.044	1.043	1.043	1.042	1.040	1.037	1.035	1.030	1.024	1.016	1.003	.988	.972	.954	.920	.886	.852	.818
MC/land	1.040	1.039	1.039	1.040	1.040	1.038	1.036	1.031	1.024	1.015	1.001	.984	.968	.955	.921	.887	.853	.819
Latitude: 18°S-36°S																		
Clear ocean	1.052	1.051	1.051	1.049	1.046	1.042	1.038	1.032	1.024	1.014	.999	.982	.964	.948	.914	.880	.846	.812
Clear land	1.060	1.059	1.058	1.056	1.052	1.048	1.043	.0136	1.027	1.015	.999	.980	.959	.937	.903	.869	.835	.801
Clear desert	1.060	1.060	1.059	1.056	1.052	1.047	1.042	1.035	1.025	1.014	.998	.979	.959	.940	.906	.872	.838	.804
PC/ocean	1.051	1.051	1.050	1.049	1.045	1.042	1.038	1.032	1.024	1.014	.999	.981	.964	.948	.914	.880	.846	.812
PC/land	1.056	1.056	1.056	1.054	1.049	1.045	1.040	1.034	1.026	1.014	.998	.980	.962	.943	.909	.876	.842	.808
MC/ocean	1.044	1.043	1.043	1.041	1.039	1.036	1.033	1.027	1.021	1.012	.999	.986	.973	.961	.927	.893	.859	.825
MC/land	1.044	1.043	1.043	1.042	1.039	1.036	1.033	1.027	1.020	1.012	.999	.985	.972	.960	.926	.892	.858	.824
Overcast	1.038	1.042	1.044	1.046	1.043	1.038	1.030	1.024	1.017	1.007	.995	.984	.975	.966	.932	.898	.864	.830
Latitude: 36°S-54°S																		
Clear ocean	1.055	1.055	1.054	1.052	1.049	1.045	1.042	1.036	1.029	1.018	1.002	.982	.959	.937	.903	.869	.835	.801
PC/ocean	1.055	1.054	1.054	1.052	1.048	1.044	1.041	1.034	1.026	1.015	.998	.980	.962	.945	.911	.877	.843	.809
PC/land	1.032	1.032	1.032	1.031	1.029	1.028	1.028	1.024	1.020	1.013	1.001	.989	.979	.971	.937	.903	.870	.836
MC/ocean	1.043	1.042	1.042	1.041	1.038	1.035	1.032	1.027	1.020	1.012	.999	.985	.972	.964	.930	.896	.862	.827
Overcast	1.031	1.030	1.029	1.028	1.024	1.021	1.018	1.011	1.003	.992	.978	.974	.990	1.022	.988	.953	.918	.884
Latitude: 54°S-72°S																		
MC/ocean	1.055	1.054	1.054	1.054	1.051	1.049	1.046	1.040	1.033	1.022	1.001	.980	.955	.931	.897	.863	.829	.795
Overcast	1.047	1.048	1.047	1.047	1.042	1.040	1.036	1.030	1.023	1.011	.996	.980	.966	.959	.925	.891	.857	.822

<sup>a</sup>MC, mostly cloudy; PC, partly cloudy.

Table 9. Limb-Darkening Models for Night for NOAA-9

Scene ID (a)	Limb-darkening model for																	
	Viewing zenith angle range, deg. of																	
	0 5	5 10	10 15	15 20	20 25	25 30	30 35	35 40	40 45	45 50	50 55	55 60	60 65	65 70	70 75	75 80	80 85	85 90
Latitude: 72°N 54°N																		
Clear land	1.048	1.046	1.044	1.042	1.039	1.035	1.033	1.027	1.020	1.012	1.000	.986	.972	.959	.928	.896	.865	.834
PC/land	1.035	1.035	1.036	1.037	1.036	1.034	1.032	1.027	1.022	1.015	1.003	.989	.973	.959	.928	.896	.865	.834
Latitude: 54°N 36°N																		
Clear ocean	1.055	1.054	1.054	1.053	1.050	1.047	1.042	1.035	1.027	1.016	1.001	.983	.962	.933	.902	.871	.840	.809
Clear land	1.046	1.046	1.045	1.044	1.041	1.037	1.033	1.027	1.021	1.013	1.001	.987	.972	.953	.922	.891	.860	.829
Clear desert	1.035	1.035	1.035	1.035	1.032	1.029	1.027	1.022	1.017	1.009	.998	.987	.979	.971	.940	.909	.878	.847
PC/ocean	1.044	1.044	1.044	1.042	1.040	1.036	1.033	1.027	1.020	1.012	.999	.985	.970	.957	.926	.895	.864	.833
PC/land	1.044	1.044	1.044	1.043	1.040	1.036	1.032	1.027	1.020	1.012	1.000	.986	.972	.958	.927	.896	.865	.834
PC/land-ocean	1.041	1.041	1.041	1.040	1.038	1.036	1.033	1.029	1.022	1.014	1.002	.987	.971	.956	.925	.894	.863	.832
MC/ocean	1.044	1.043	1.042	1.041	1.039	1.035	1.032	1.027	1.022	1.014	1.004	.992	.974	.950	.919	.888	.857	.826
Latitude: 36°N 18°N																		
Clear ocean	1.055	1.054	1.053	1.052	1.048	1.044	1.040	1.033	1.025	1.015	1.000	.982	.963	.941	.910	.879	.848	.817
Clear desert	1.048	1.047	1.047	1.045	1.042	1.038	1.035	1.029	1.022	1.013	1.000	.985	.969	.950	.919	.888	.857	.827
Clear land-ocean	1.047	1.045	1.044	1.043	1.040	1.037	1.034	1.028	1.021	1.011	.999	.985	.970	.955	.924	.893	.862	.831
PC/ocean	1.052	1.051	1.051	1.049	1.046	1.042	1.038	1.031	1.024	1.014	1.000	.983	.965	.946	.915	.884	.853	.822
PC/land	1.046	1.045	1.046	1.045	1.042	1.039	1.035	1.030	1.023	1.015	1.002	.985	.967	.948	.917	.886	.855	.824
MC/ocean	1.041	1.040	1.040	1.039	1.037	1.035	1.032	1.027	1.021	1.013	1.001	.988	.973	.957	.926	.895	.864	.833
Latitude: 18°N 0°																		
Clear ocean	1.056	1.055	1.054	1.053	1.050	1.046	1.042	1.035	1.027	1.016	1.000	.982	.959	.935	.904	.873	.842	.811
Clear desert	1.059	1.057	1.055	1.053	1.049	1.045	1.041	1.035	1.027	1.016	1.000	.982	.960	.936	.905	.875	.844	.813
PC/ocean	1.057	1.056	1.055	1.053	1.050	1.045	1.041	1.034	1.026	1.015	1.000	.981	.960	.938	.907	.876	.845	.814
MC/ocean	1.053	1.053	1.052	1.050	1.047	1.043	1.039	1.032	1.025	1.015	.999	.981	.962	.944	.913	.882	.851	.820
Overcast	1.035	1.035	1.035	1.035	1.034	1.034	1.034	1.030	1.026	1.018	1.004	.987	.970	.953	.929	.898	.858	.820
Latitude: 0° 18°N																		
Clear ocean	1.052	1.051	1.050	1.049	1.046	1.043	1.039	1.033	1.025	1.015	1.001	.983	.964	.943	.912	.881	.850	.819
Clear land	1.048	1.048	1.047	1.045	1.042	1.039	1.035	1.029	1.022	1.014	1.001	.986	.969	.952	.921	.890	.859	.828
PC/ocean	1.049	1.048	1.048	1.047	1.043	1.040	1.036	1.030	1.023	1.014	1.000	.984	.966	.948	.917	.886	.855	.824
PC/land	1.040	1.040	1.040	1.039	1.037	1.034	1.031	1.027	1.021	1.013	1.002	.988	.974	.960	.929	.898	.867	.836
MC/ocean	1.042	1.042	1.042	1.041	1.038	1.036	1.033	1.028	1.021	1.013	1.001	.986	.971	.956	.925	.894	.863	.832
MC/land	1.043	1.043	1.043	1.043	1.042	1.039	1.035	1.029	1.023	1.013	.998	.981	.967	.957	.926	.895	.864	.833
Latitude: 18°S 36°S																		
Clear ocean	1.051	1.050	1.049	1.048	1.046	1.043	1.040	1.034	1.027	1.017	1.002	.983	.962	.939	.908	.878	.847	.816
Clear land	1.038	1.037	1.038	1.037	1.035	1.032	1.030	1.026	1.020	1.012	1.001	.988	.974	.961	.930	.899	.868	.837
Clear desert	1.037	1.037	1.037	1.036	1.034	1.031	1.029	1.025	1.020	1.014	1.004	.991	.975	.960	.929	.898	.867	.836
PC/ocean	1.049	1.048	1.048	1.046	1.043	1.040	1.036	1.030	1.023	1.014	1.001	.985	.966	.947	.916	.885	.854	.823
PC/land	1.035	1.035	1.035	1.035	1.032	1.030	1.028	1.024	1.019	1.012	1.002	.990	.977	.965	.934	.903	.872	.841
MC/ocean	1.035	1.035	1.035	1.034	1.033	1.031	1.029	1.025	1.020	1.013	1.003	.990	.977	.964	.933	.902	.871	.840

<sup>a</sup>MC, mostly cloudy; PC, partly cloudy.

Table 9. Concluded

Scene ID (a)	Limb-darkening model for ---																		
	Viewing zenith angle range, deg, of—																		
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	
Latitude: 36°S-54°S																			
Clear ocean	1.059	1.058	1.057	1.056	1.052	1.048	1.044	1.037	1.028	1.017	1.000	.979	.957	.932	.901	.870	.839	.808	
PC/ocean	1.051	1.051	1.051	1.050	1.047	1.044	1.040	1.033	1.026	1.016	1.002	.984	.963	.941	.910	.879	.848	.817	
MC/ocean	1.041	1.041	1.041	1.041	1.039	1.036	1.032	1.026	1.020	1.012	1.001	.987	.972	.956	.925	.894	.863	.832	
Overcast	1.016	1.016	1.017	1.017	1.016	1.014	1.013	1.009	1.006	1.001	.993	.984	.979	.981	.983	.985	.988	.991	
Latitude: 54°S-72°S																			
Clear snow	.997	.997	1.000	1.001	1.001	1.001	1.003	1.002	1.001	1.000	.994	.988	.986	.994	1.003	1.018	1.038	1.056	
MC/ocean	1.047	1.046	1.047	1.045	1.042	1.039	1.035	1.028	1.021	1.011	.998	.983	.968	.954	.923	.892	.861	.830	
MC/land-ocean	1.037	1.037	1.037	1.036	1.034	1.032	1.029	1.025	1.019	1.013	1.003	.992	.978	.961	.930	.899	.868	.837	
Overcast	1.018	1.018	1.019	1.019	1.017	1.015	1.014	1.010	1.006	1.001	.992	.984	.979	.980	.980	.981	.983	.986	
Latitude: 72°S-90°S																			
Clear snow	.995	.994	.996	.997	.997	.998	1.001	1.001	1.001	1.000	.993	.986	.985	.997	1.009	1.030	1.057	1.083	
Overcast	.992	.992	.994	.996	.995	.996	.999	.998	.998	.996	.990	.986	.988	1.003	1.017	1.039	1.068	1.095	

<sup>a</sup>MC, mostly cloudy; PC, partly cloudy.

Table 10. Mean Limb-Darkening Models for August 1985

Viewing zenith angle range, deg	Average limb-darkening models for—			
	ERBS		NOAA-9	
	Day	Night	Day	Night
0-5	1.055	1.052	1.053	1.046
5-10	1.055	1.051	1.052	1.046
10-15	1.053	1.049	1.052	1.045
15-20	1.051	1.048	1.050	1.044
20-25	1.050	1.045	1.047	1.041
25-30	1.045	1.042	1.043	1.038
30-35	1.039	1.037	1.040	1.035
35-40	1.032	1.030	1.033	1.030
40-45	1.024	1.023	1.025	1.023
45-50	1.015	1.014	1.015	1.014
50-55	1.002	1.004	1.000	1.001
55-60	0.987	0.989	0.982	0.986
60-65	0.966	0.970	0.963	0.969
65-70	0.940	0.944	0.945	0.951
70-75	0.906	0.910	0.911	0.920
75-80	0.872	0.876	0.877	0.889
80-85	0.838	0.842	0.843	0.858
85-90	0.805	0.809	0.809	0.827

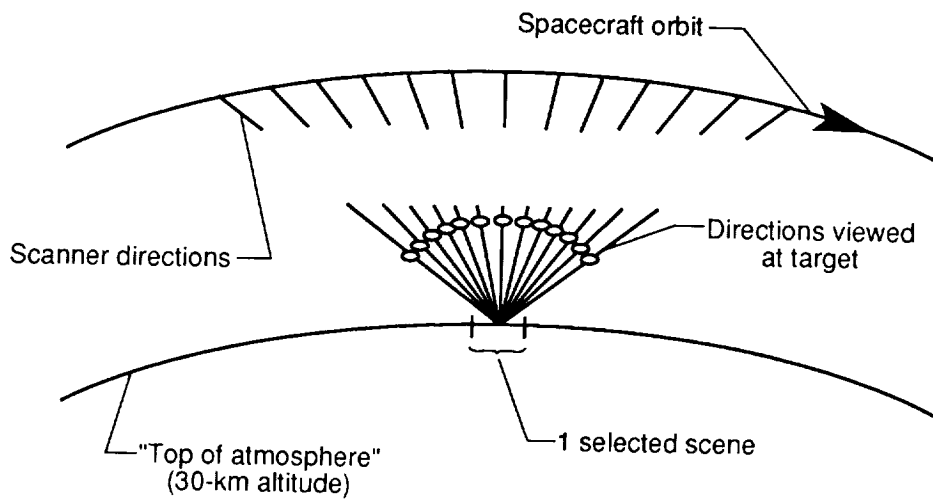


Figure 1. Use of along-track scanning for determining limb-darkening functions.

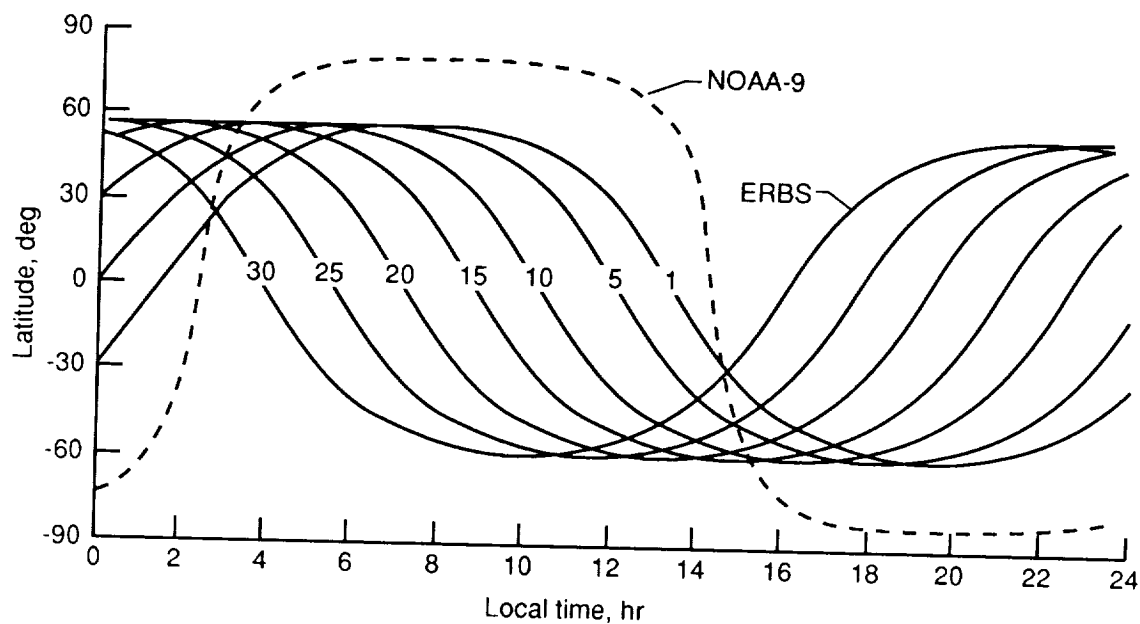


Figure 2. Local time-latitude coverage for ERBS and NOAA-9 for August 1985. Numbers on ERBS orbit indicate the dates of the month.

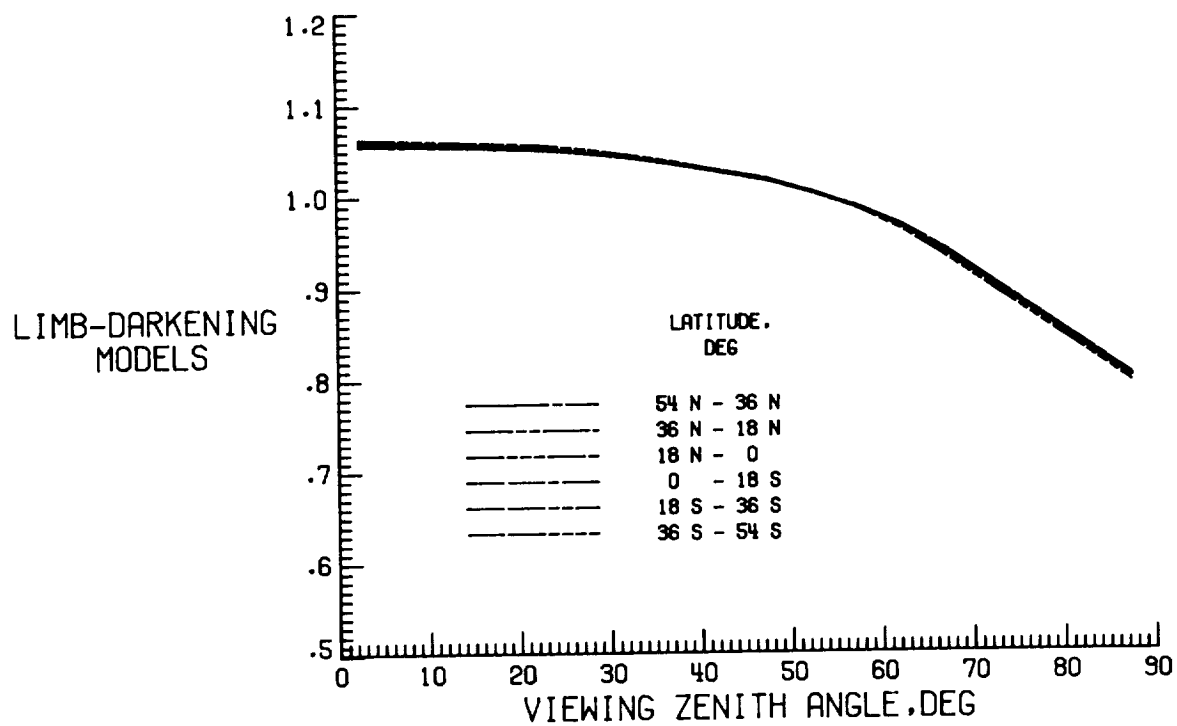


Figure 3. Limb-darkening models for clear ocean for day for ERBS.

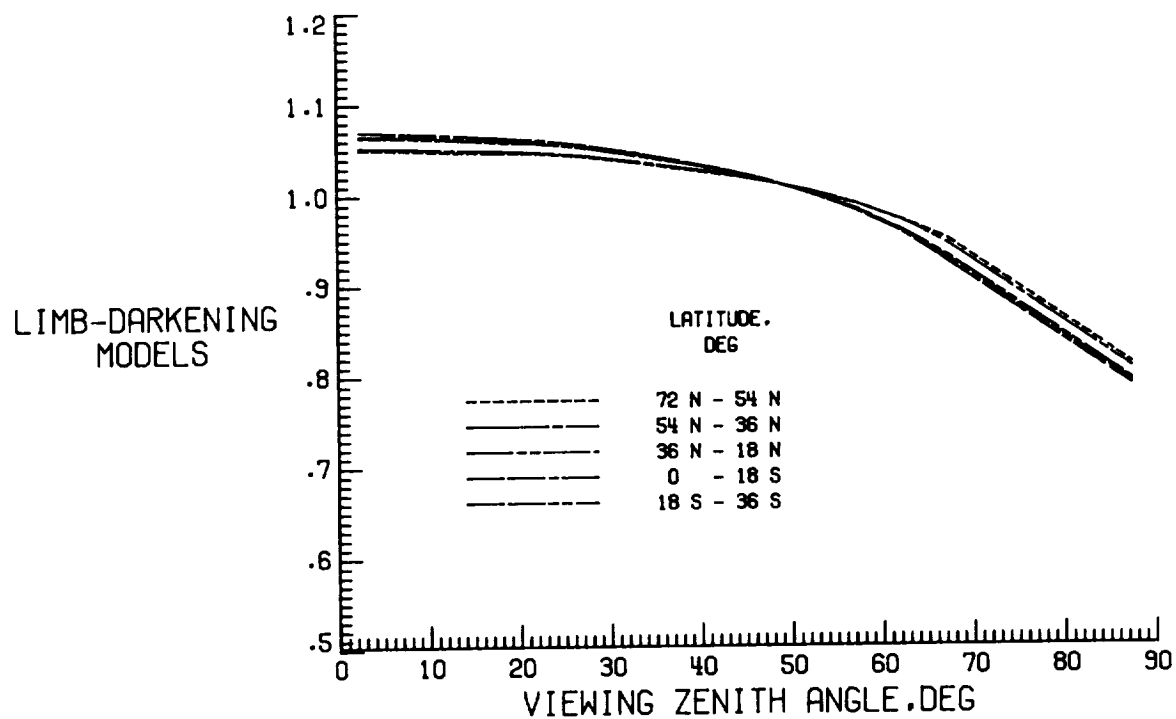


Figure 4. Limb-darkening models for clear land for day for ERBS.

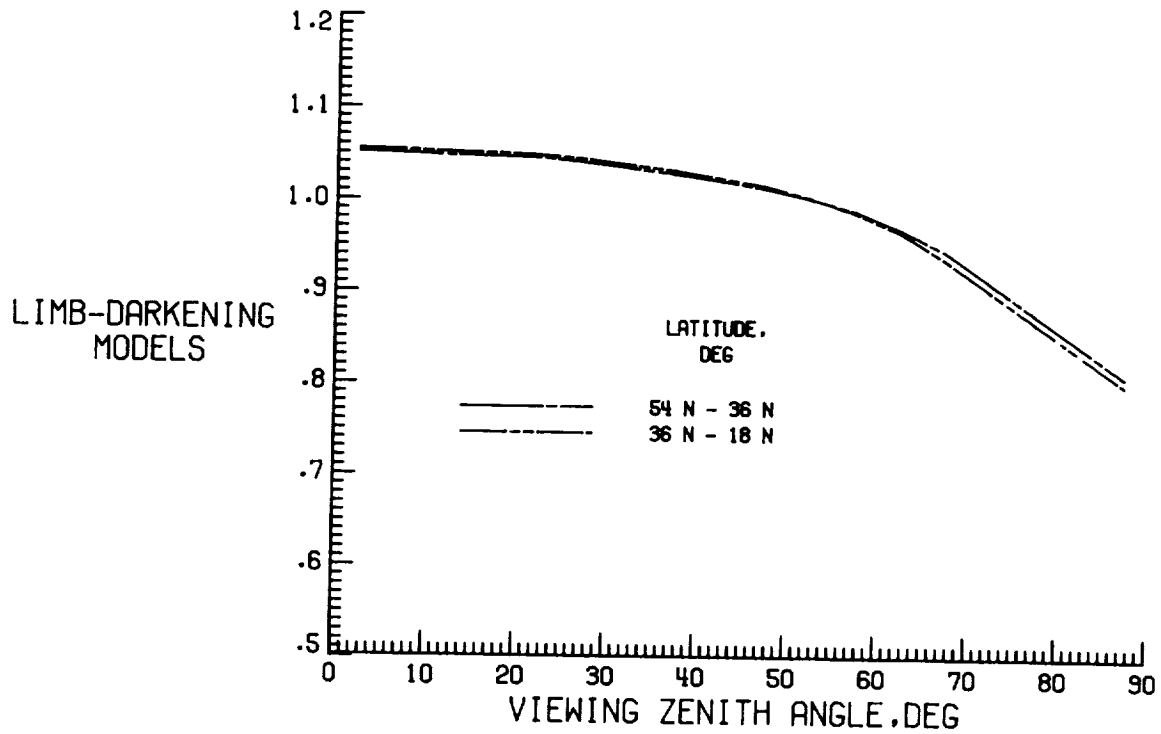


Figure 5. Limb-darkening models for clear land-ocean mix for day for ERBS.

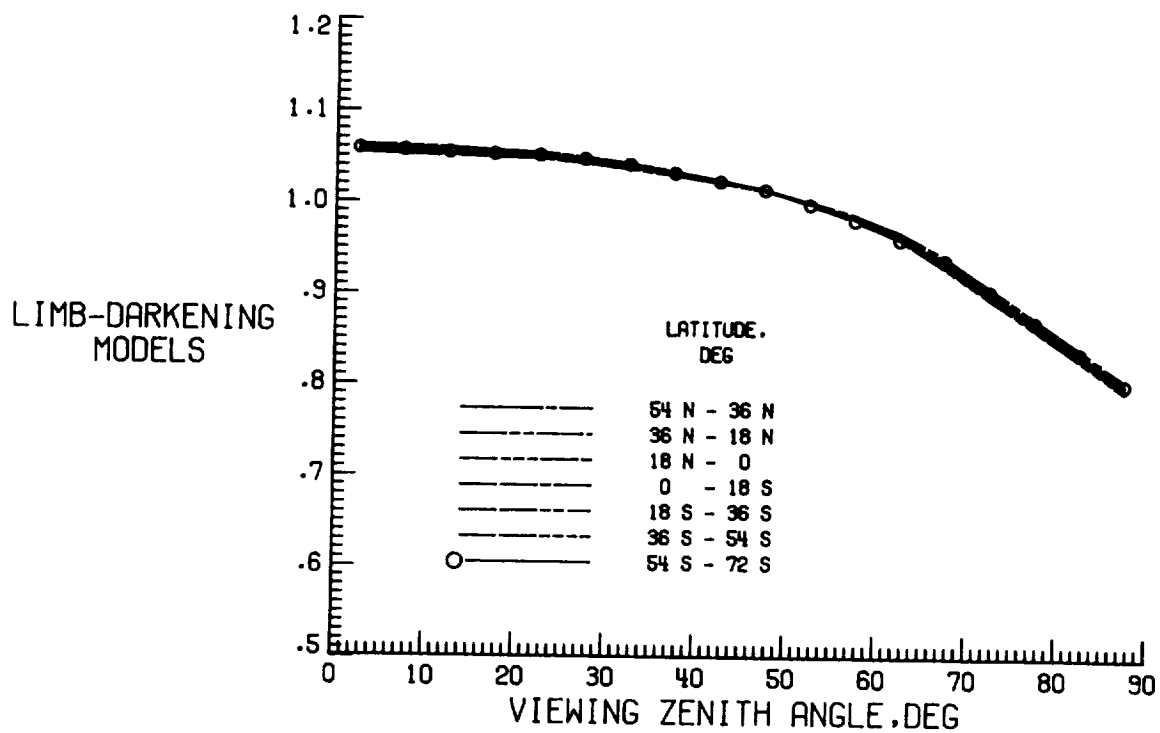


Figure 6. Limb-darkening models for partly cloudy over ocean for day for ERBS.



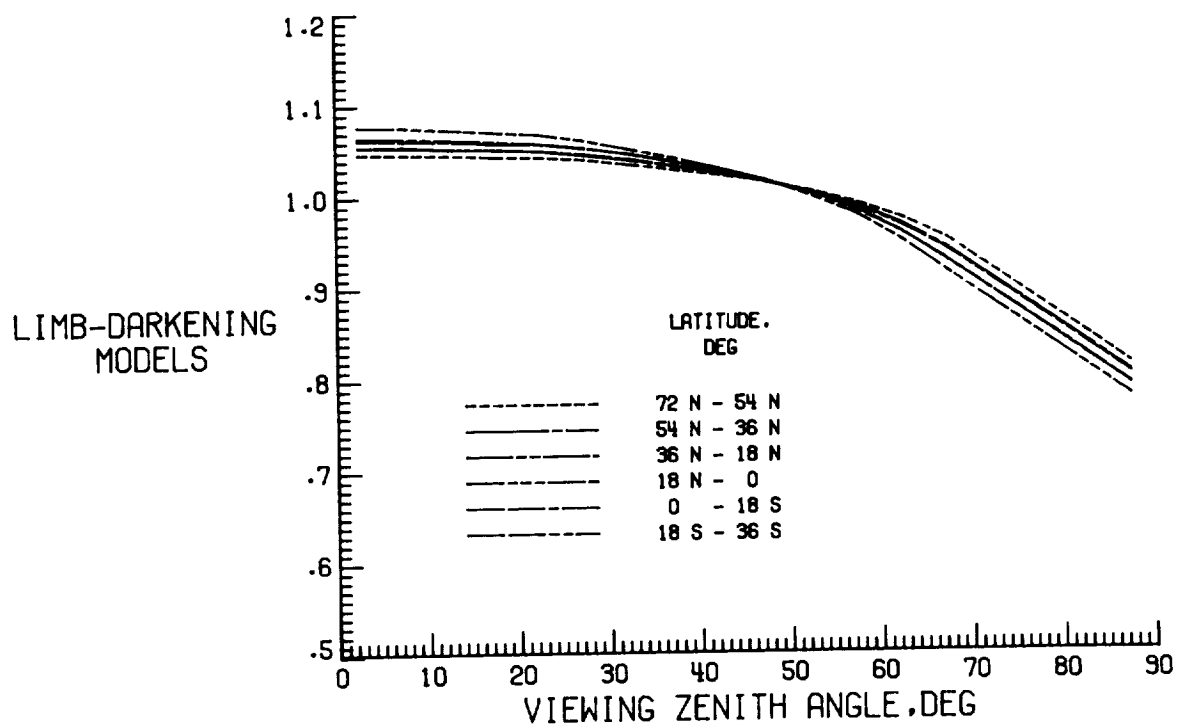


Figure 7. Limb-darkening models for partly cloudy over land for day for ERBS.

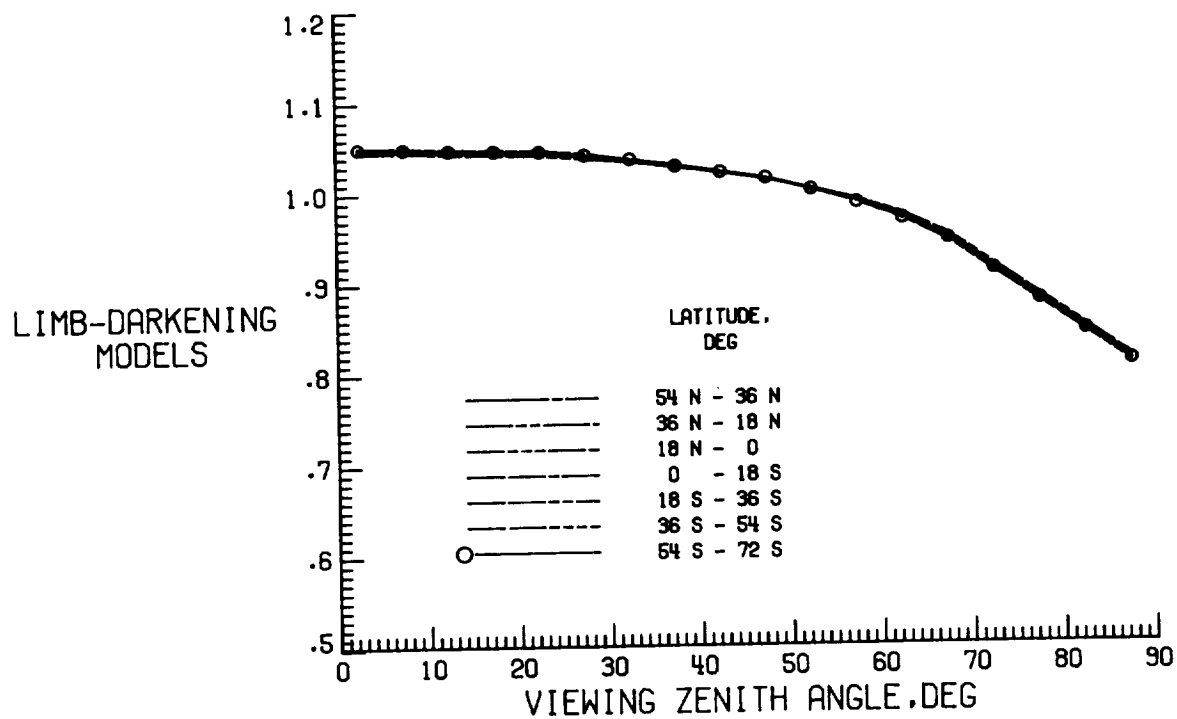


Figure 8. Limb-darkening models for mostly cloudy over ocean for day for ERBS.

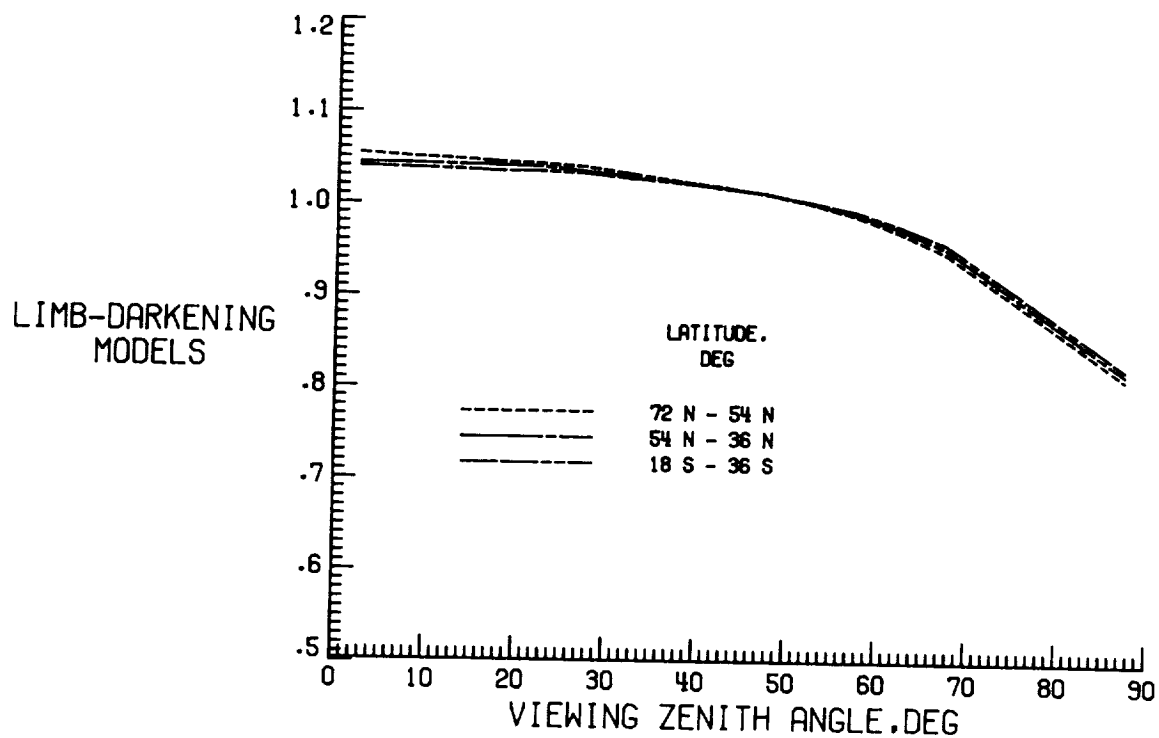


Figure 9. Limb-darkening models for mostly cloudy over land for day for ERBS.

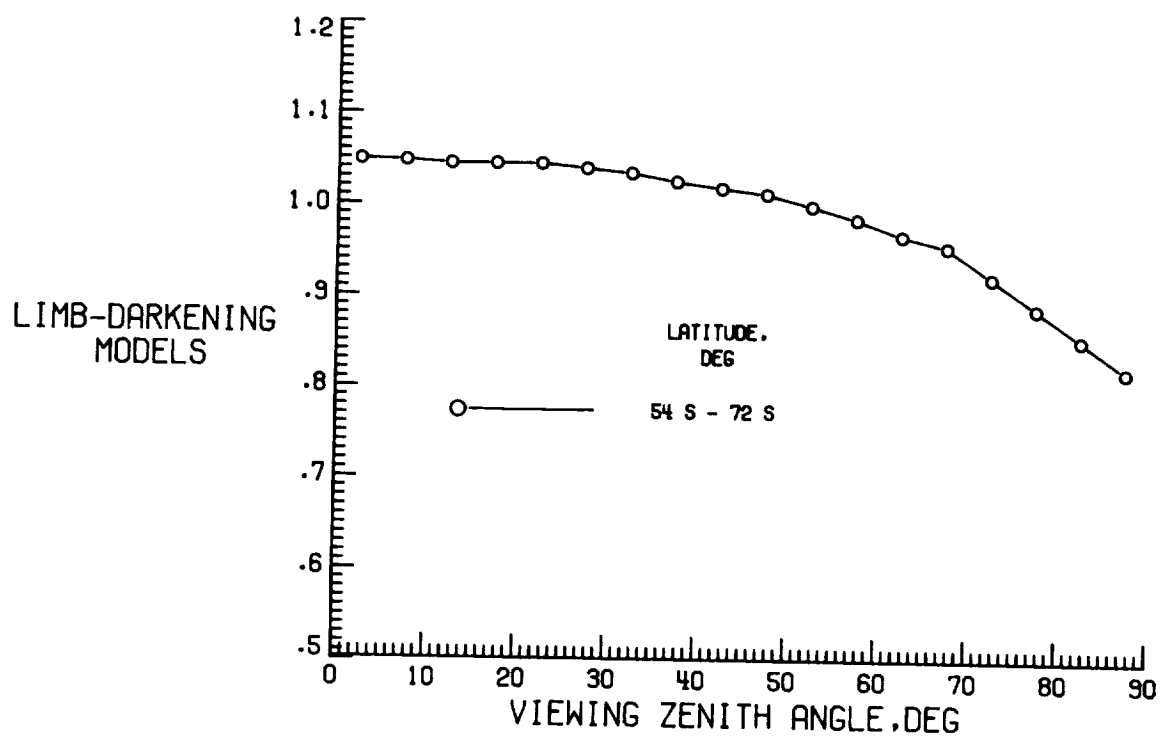


Figure 10. Limb-darkening models for overcast for day for ERBS.

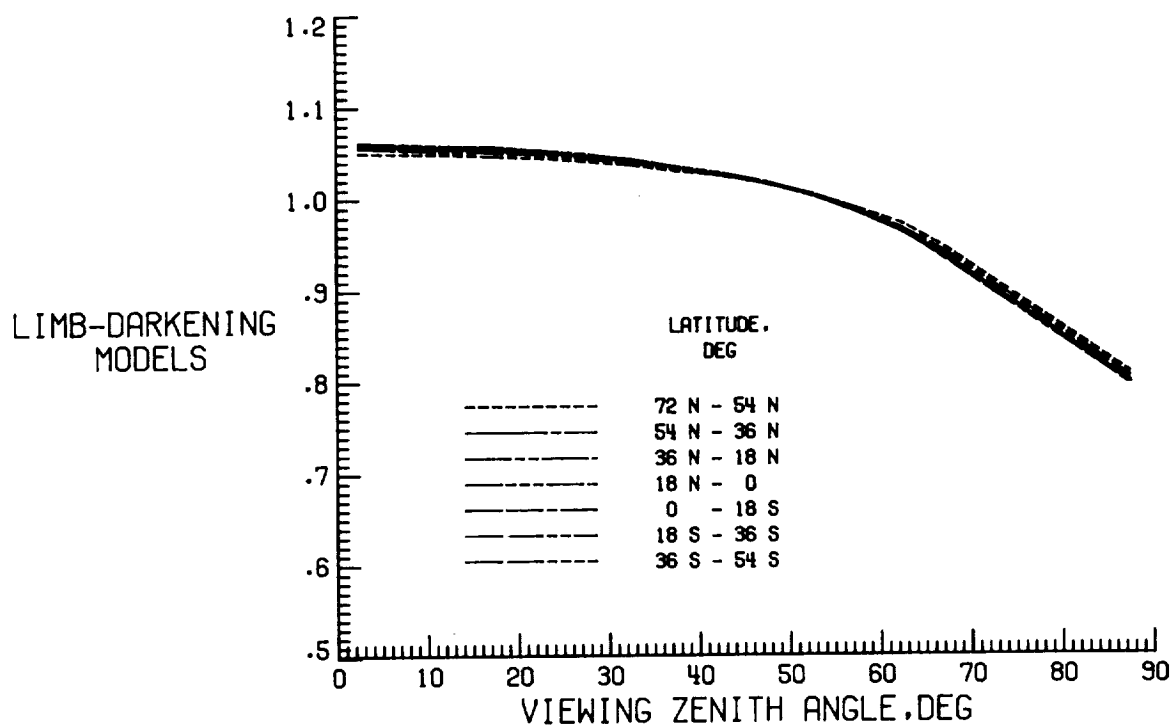


Figure 11. Limb-darkening models for clear ocean for night for ERBS.

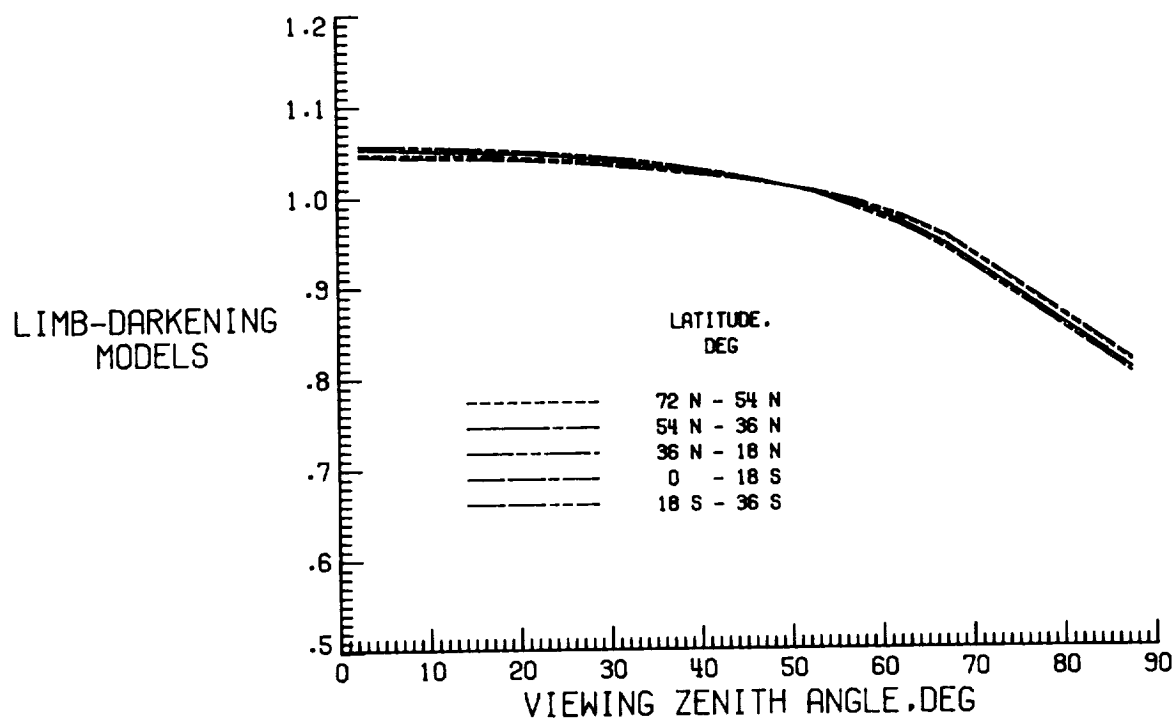


Figure 12. Limb-darkening models for clear land for night for ERBS.

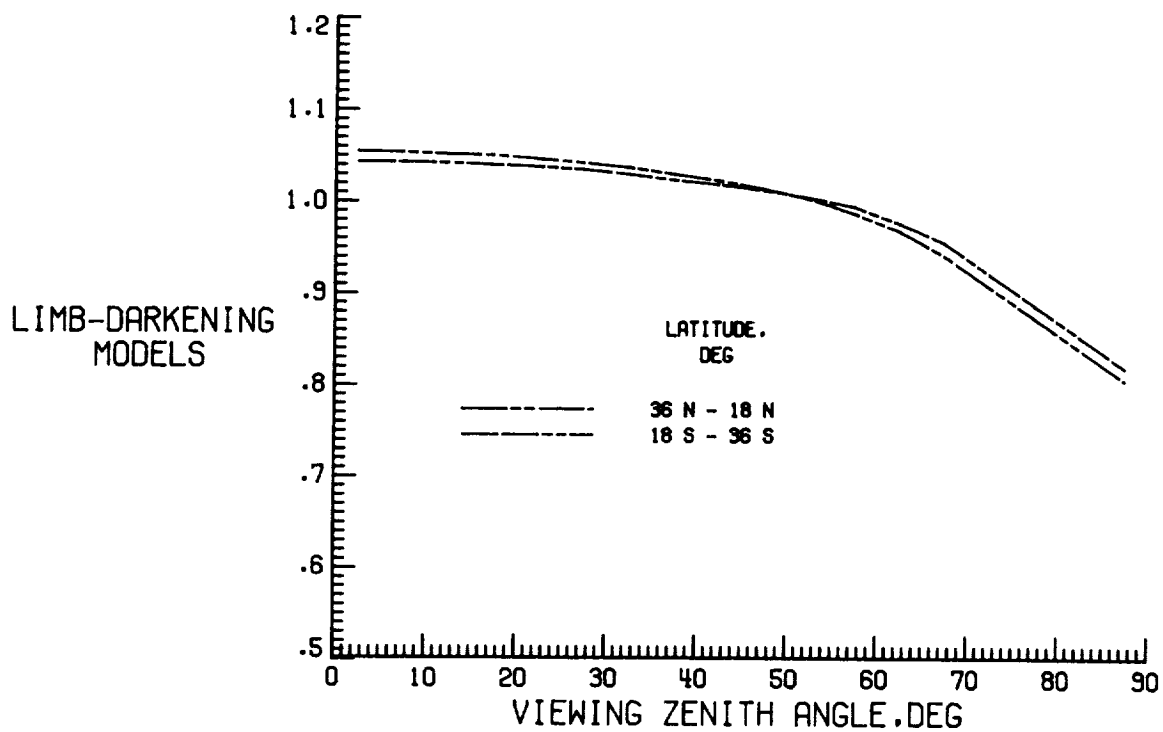


Figure 13. Limb-darkening models for clear desert for night for ERBS.

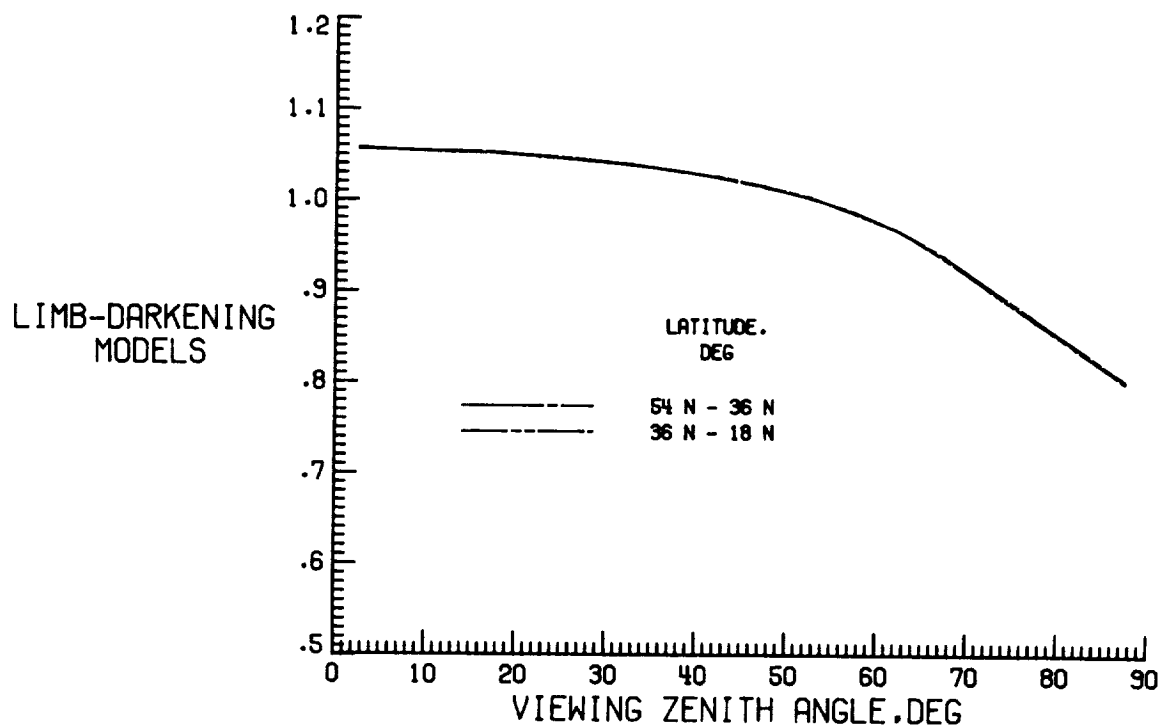


Figure 14. Limb-darkening models for clear land-ocean mix for night for ERBS.

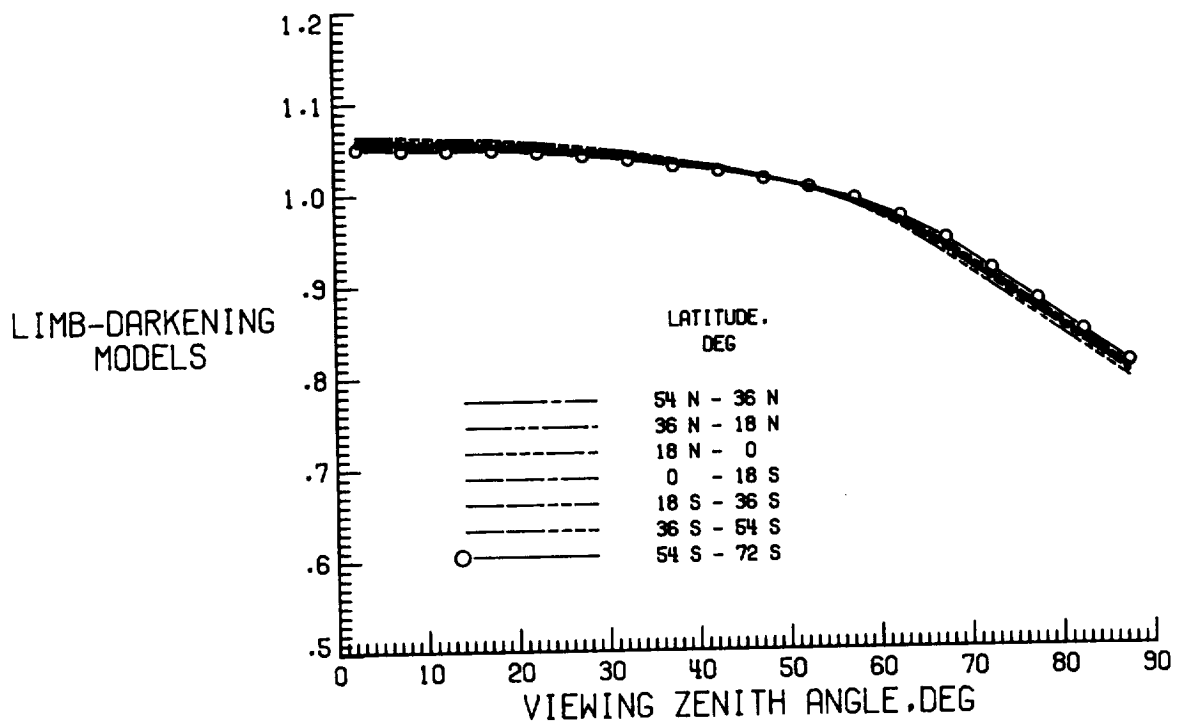


Figure 15. Limb-darkening models for partly cloudy over ocean for night for ERBS.

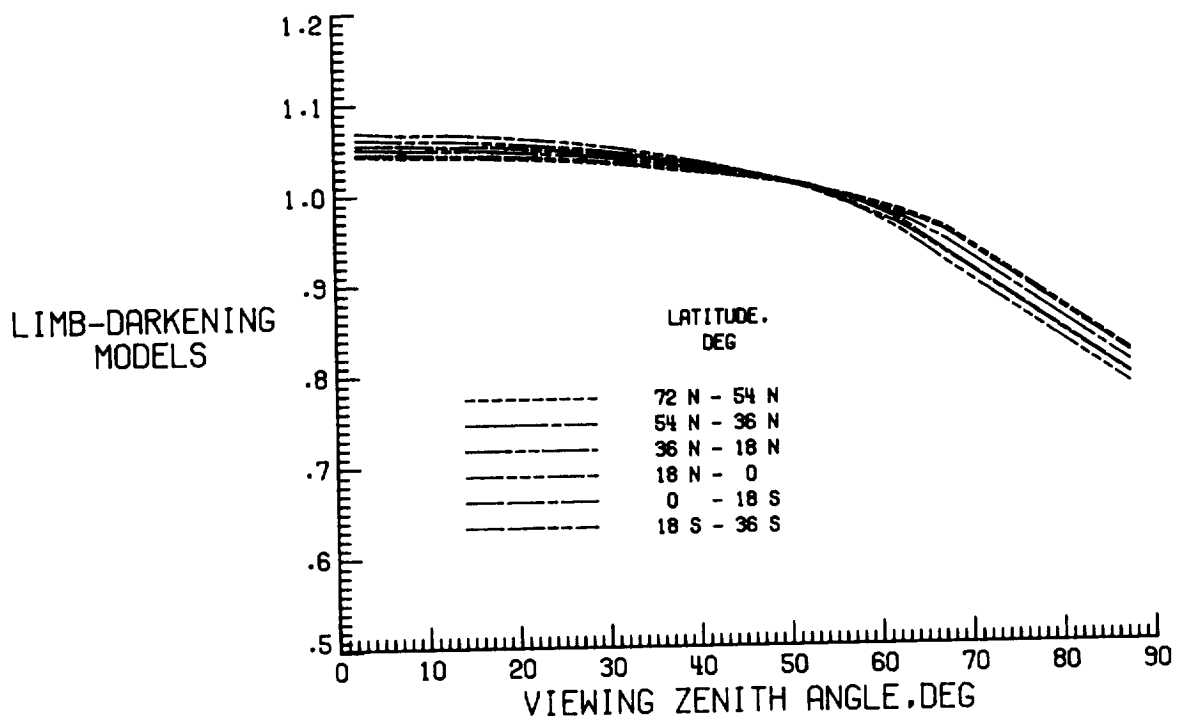


Figure 16. Limb-darkening models for partly cloudy over land for night for ERBS.

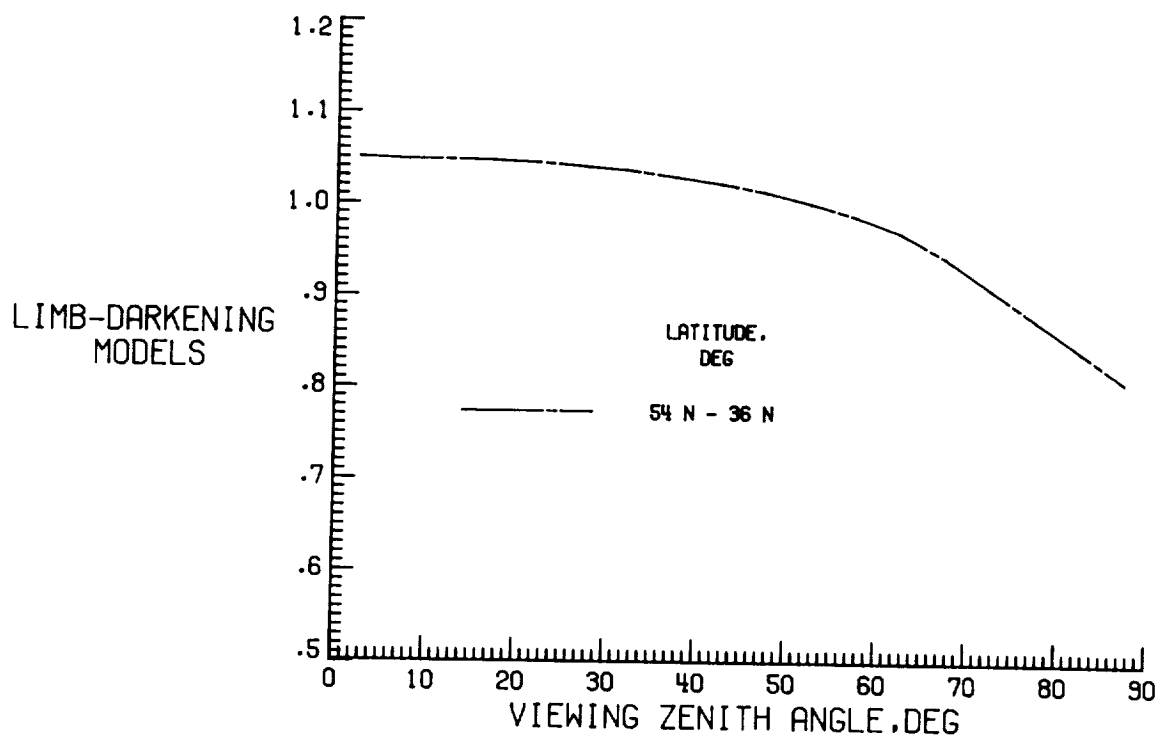


Figure 17. Limb-darkening models for partly cloudy over land-ocean mix for night for ERBS.

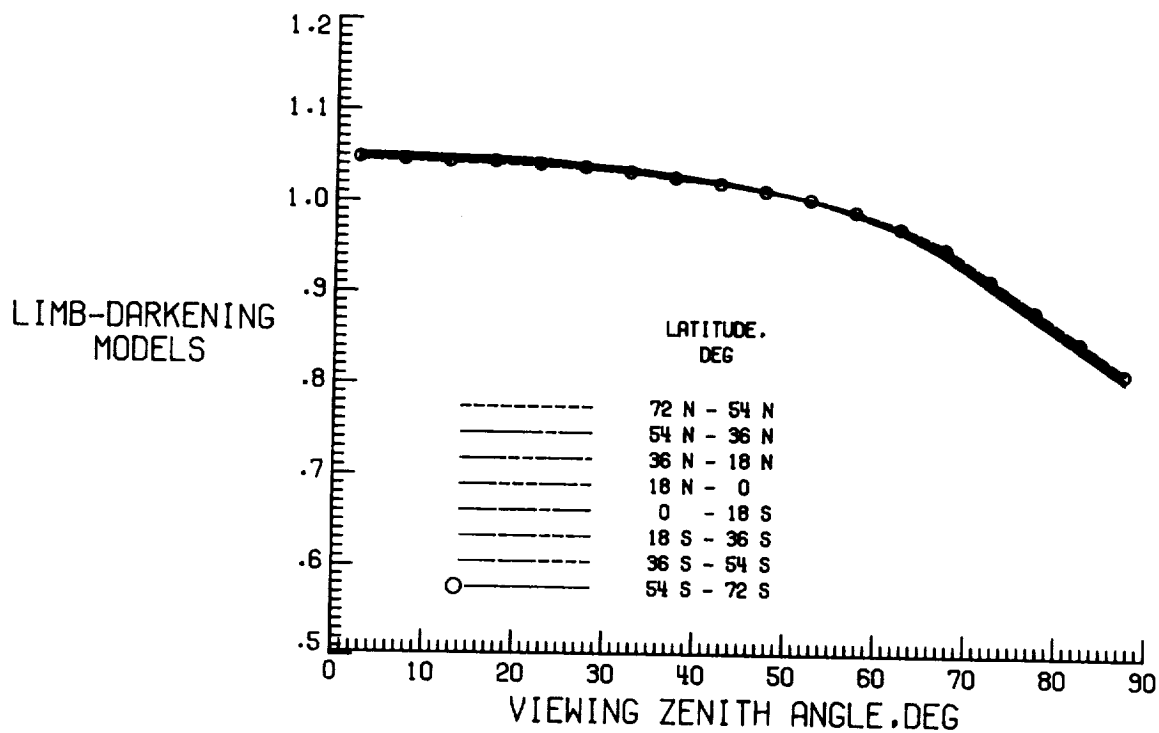


Figure 18. Limb-darkening models for mostly cloudy over ocean for night for ERBS.

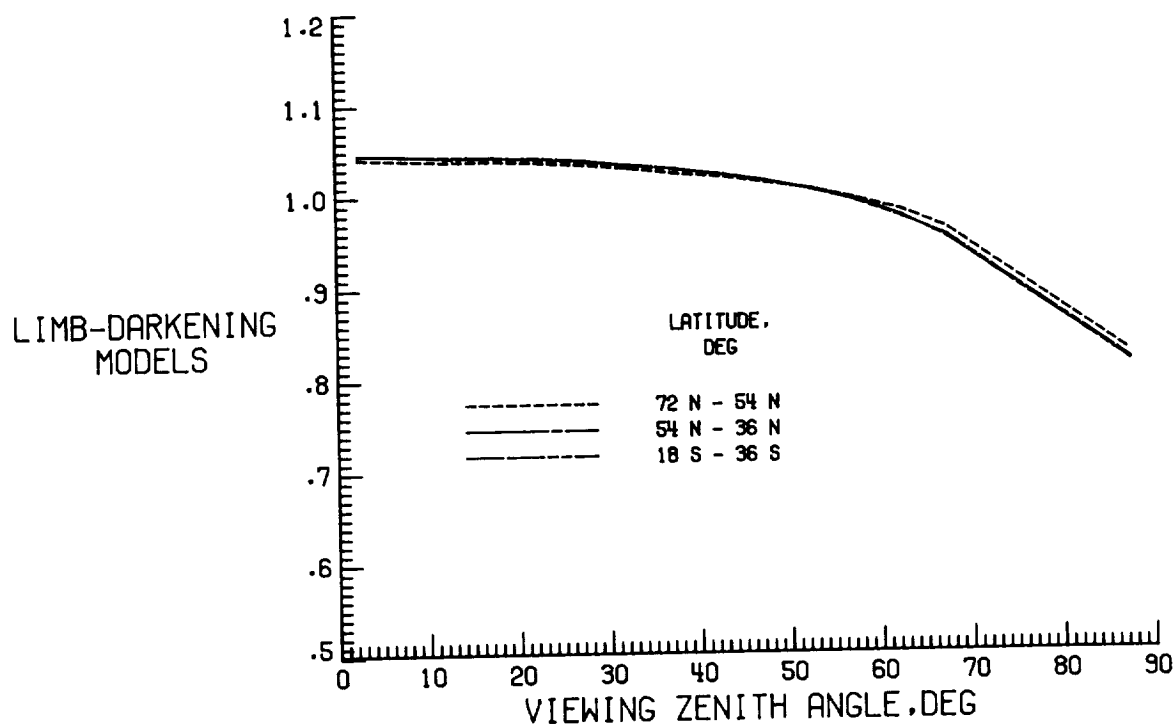


Figure 19. Limb-darkening models for mostly cloudy over land for night for ERBS.

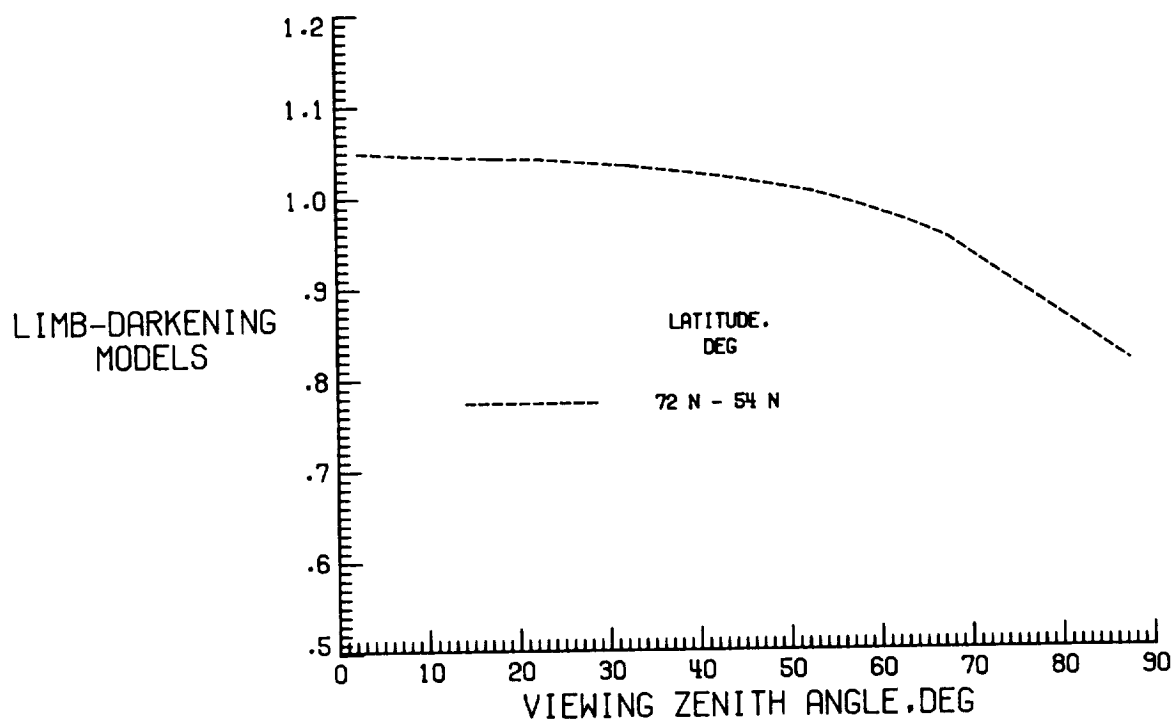


Figure 20. Limb-darkening models for mostly cloudy over land-ocean mix for night ERBS.

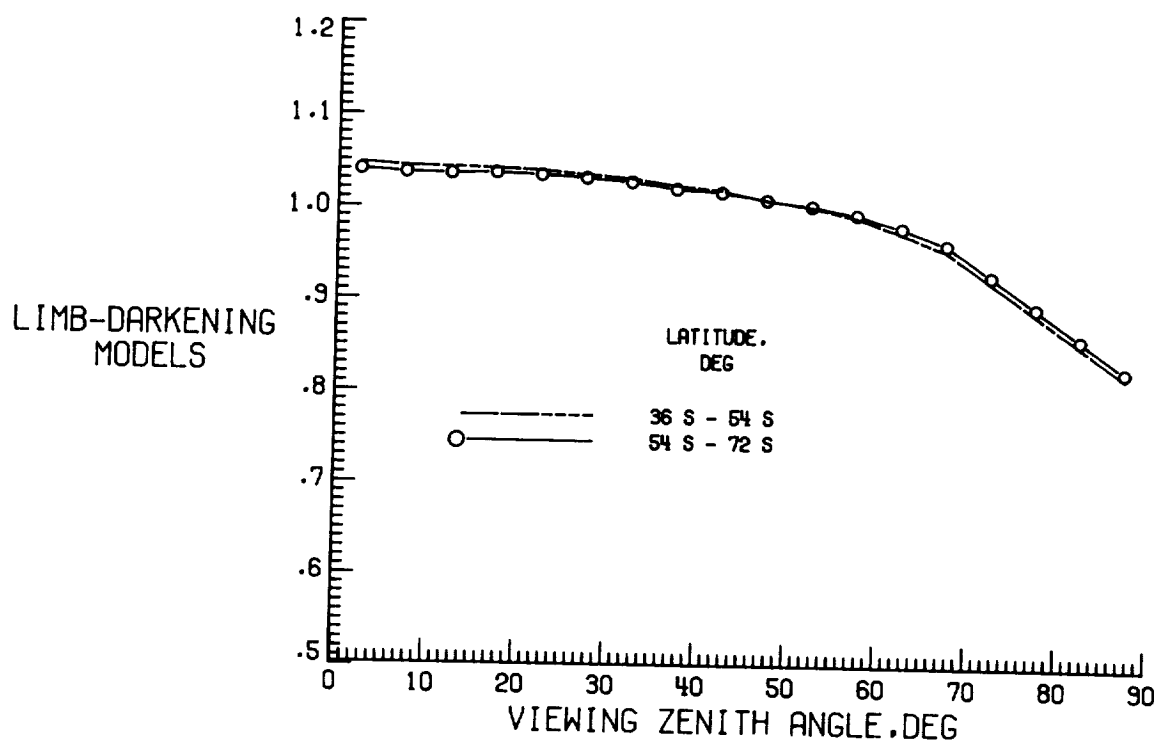


Figure 21. Limb-darkening models for overcast for night for ERBS.

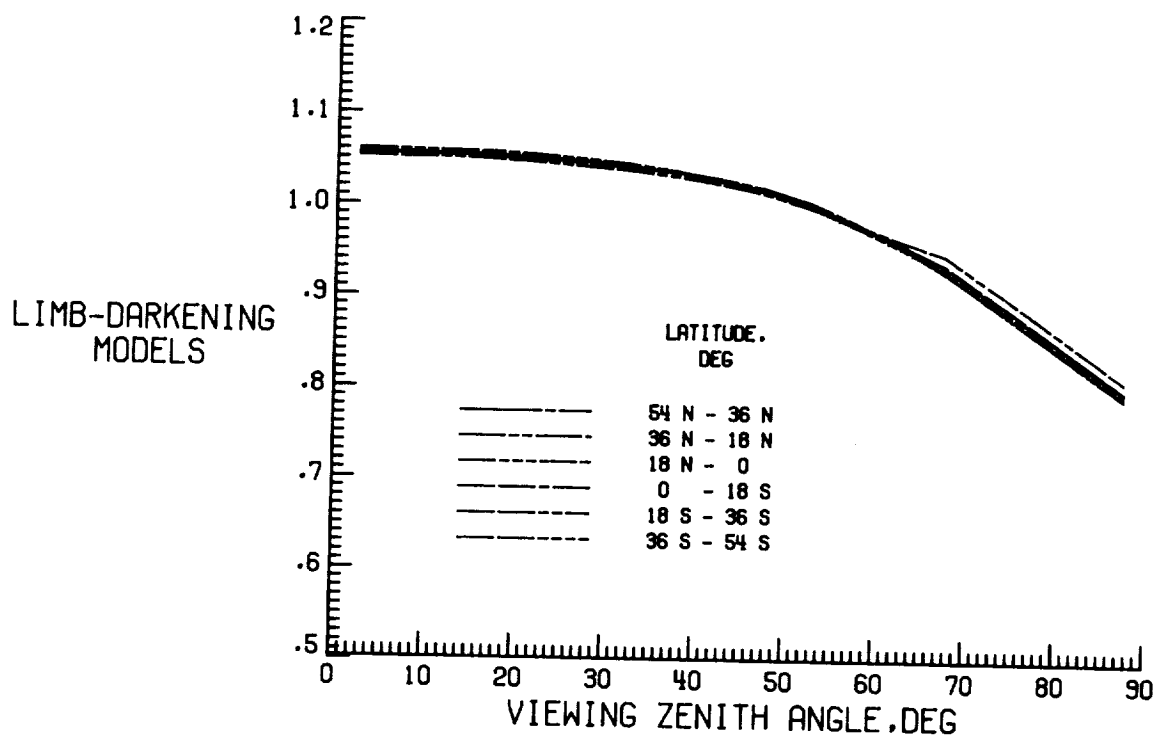


Figure 22. Limb-darkening models for clear ocean for day for NOAA-9.



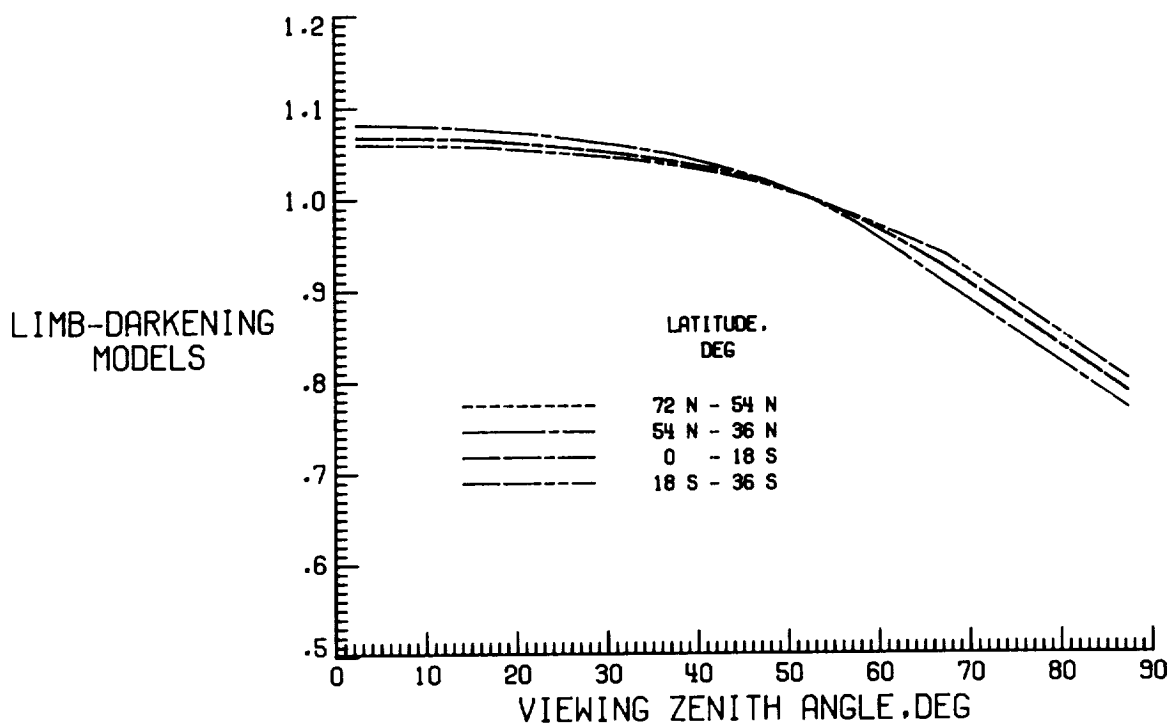


Figure 23. Limb-darkening models for clear land for day for NOAA-9.

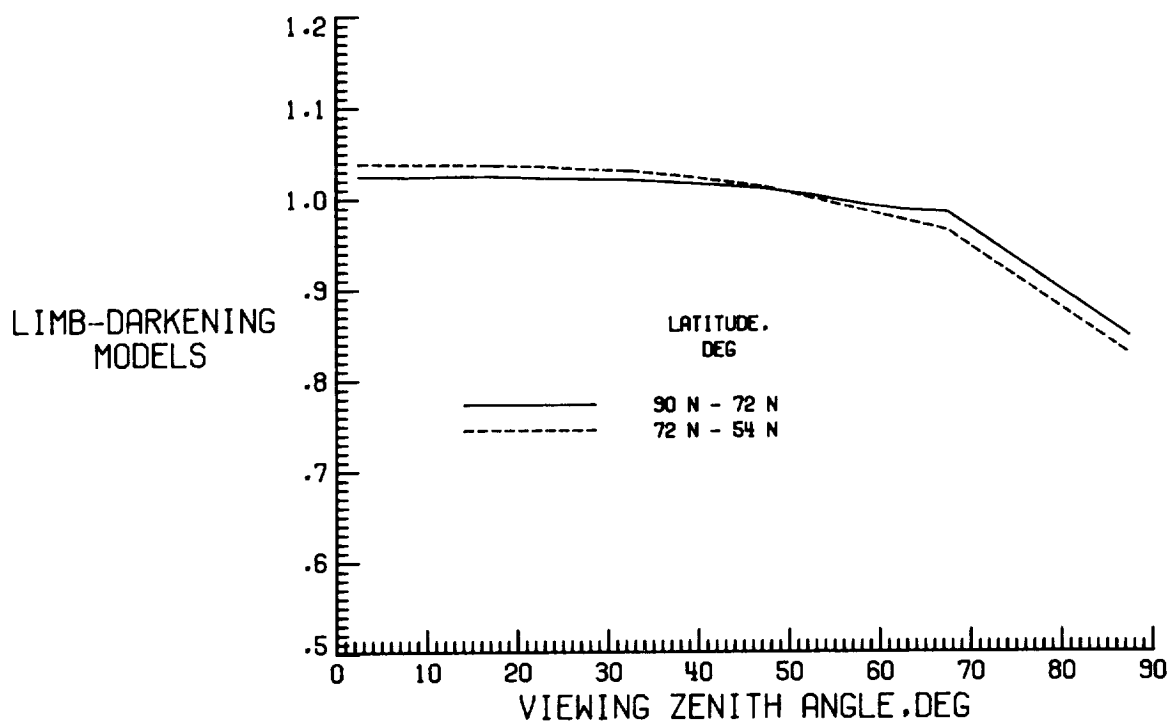


Figure 24. Limb-darkening models for clear snow for day for NOAA-9.

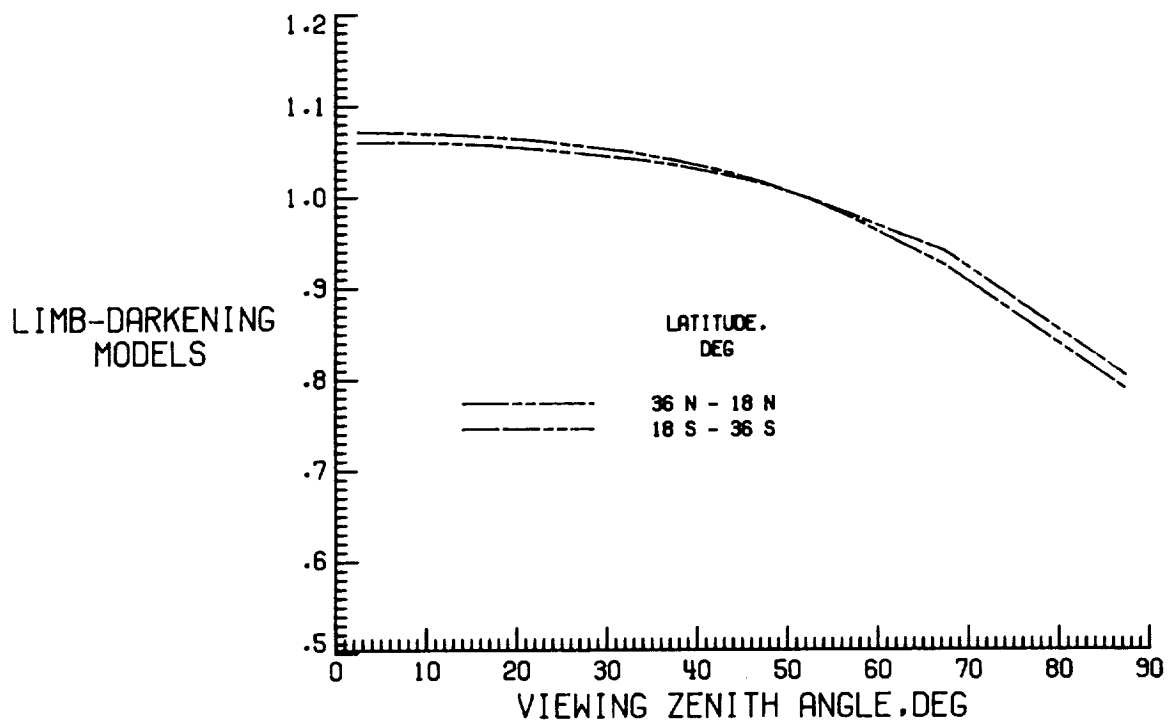


Figure 25. Limb-darkening models for clear desert for day for NOAA-9.

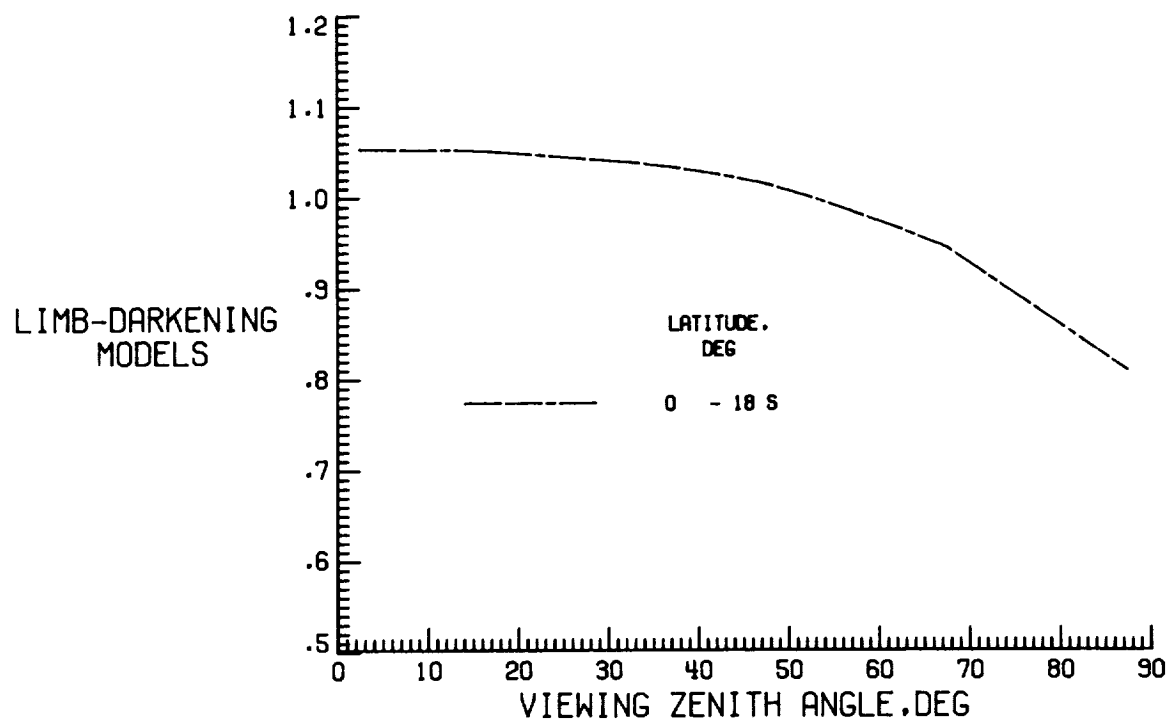


Figure 26. Limb-darkening models for clear land-ocean mix for day for NOAA-9.

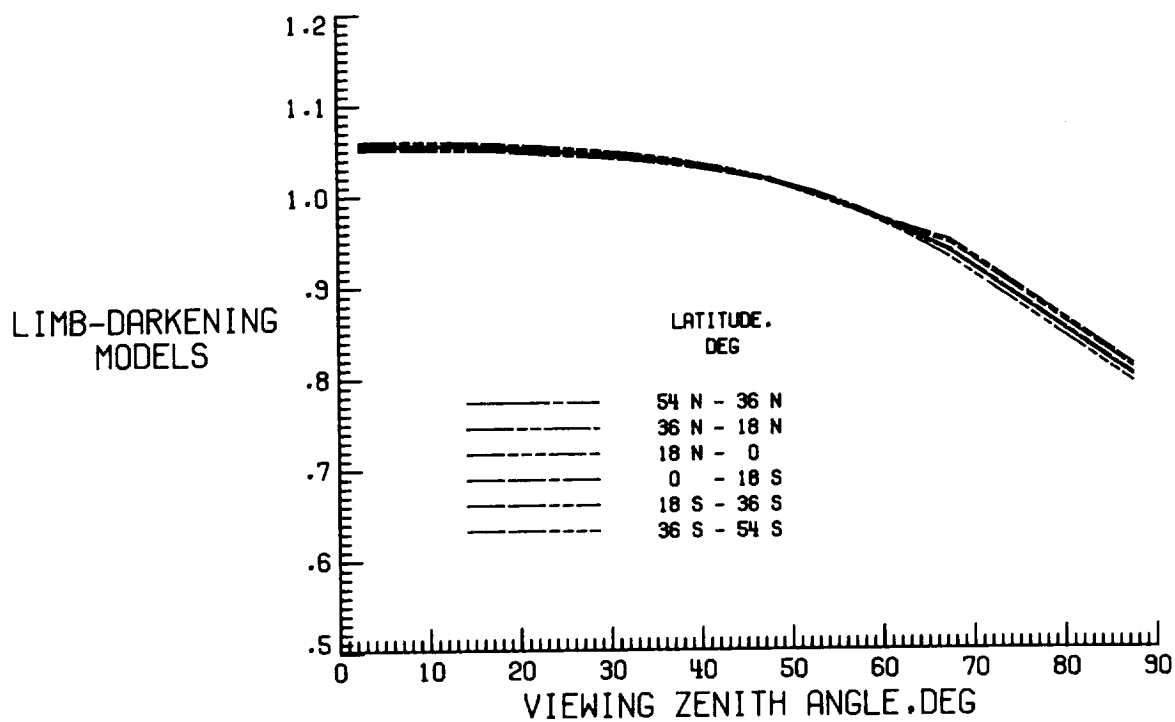


Figure 27. Limb-darkening models for partly cloudy over ocean for day for NOAA-9.

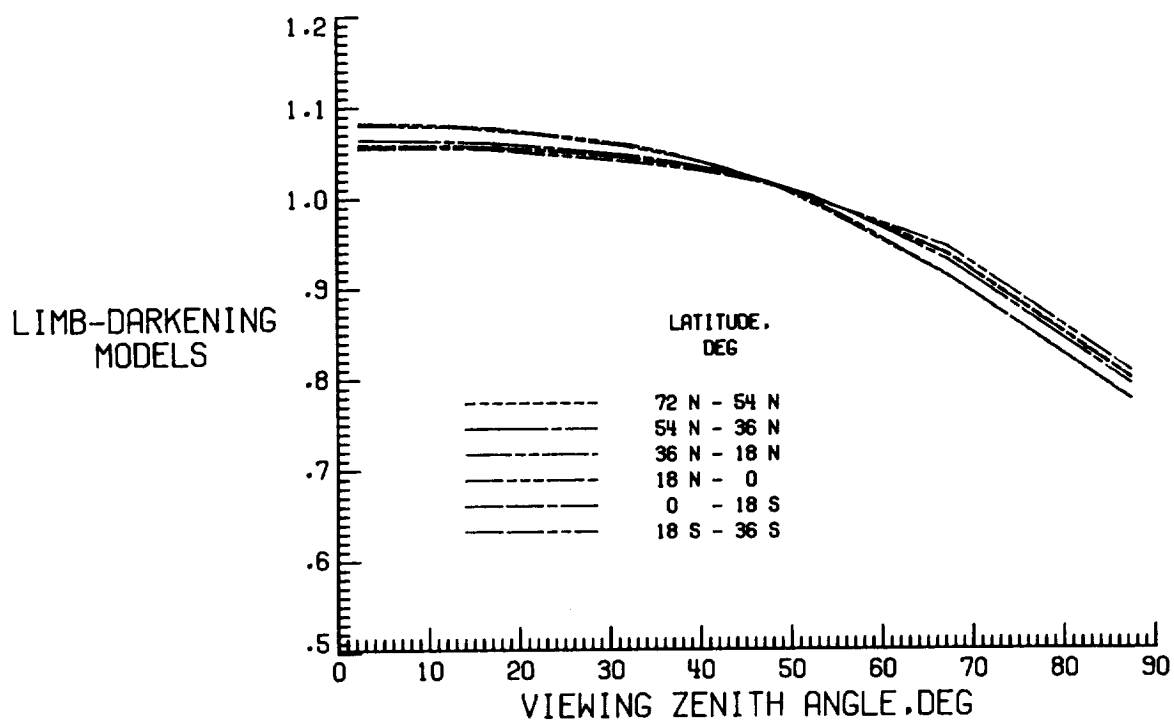


Figure 28. Limb-darkening models for partly cloudy over land for day for NOAA-9.

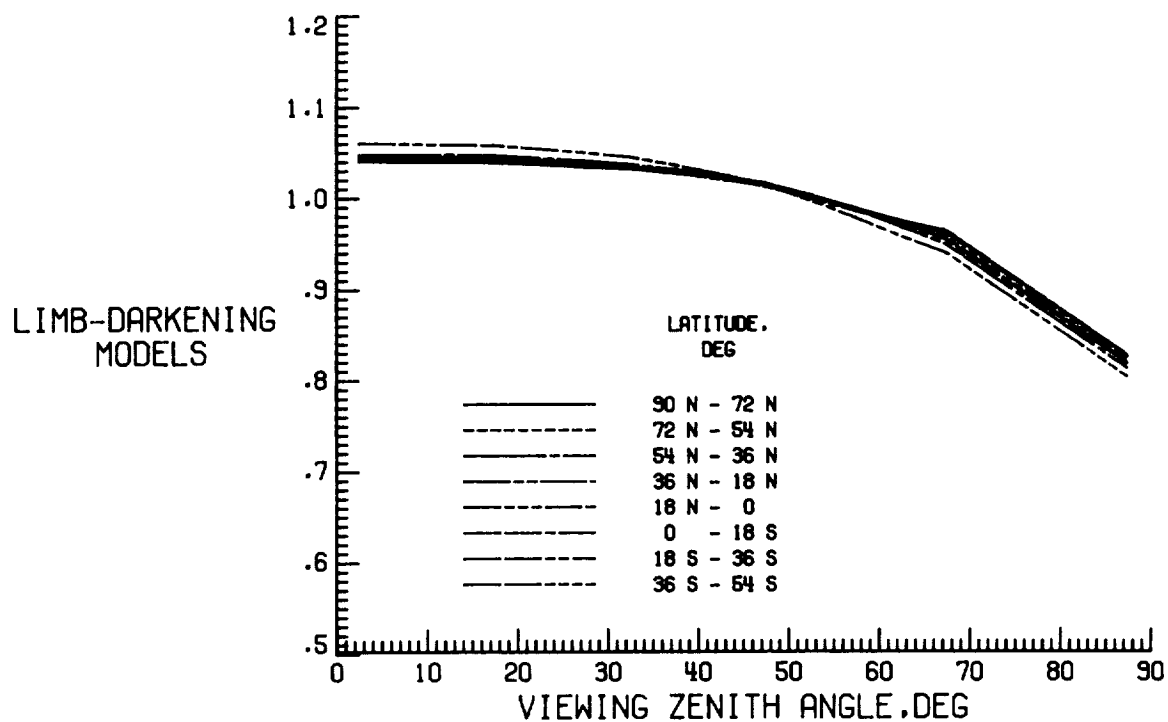


Figure 29. Limb-darkening models for mostly cloudy over ocean for day for NOAA-9.

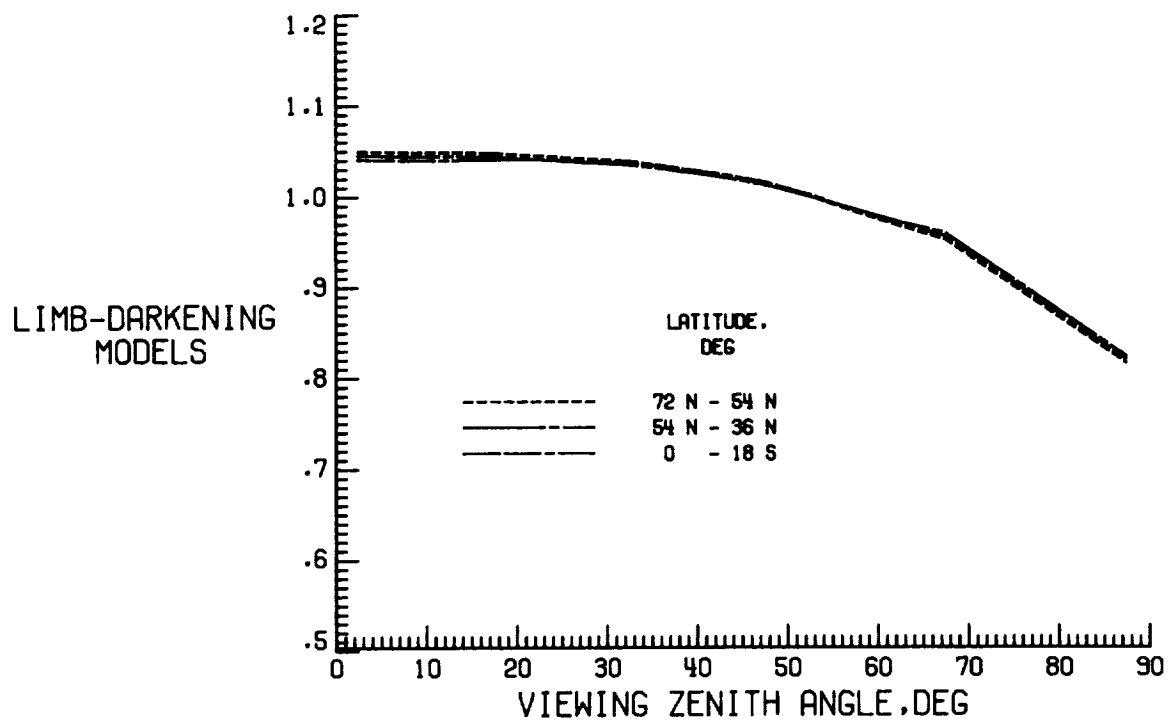


Figure 30. Limb-darkening models for mostly cloudy over land for day for NOAA-9.

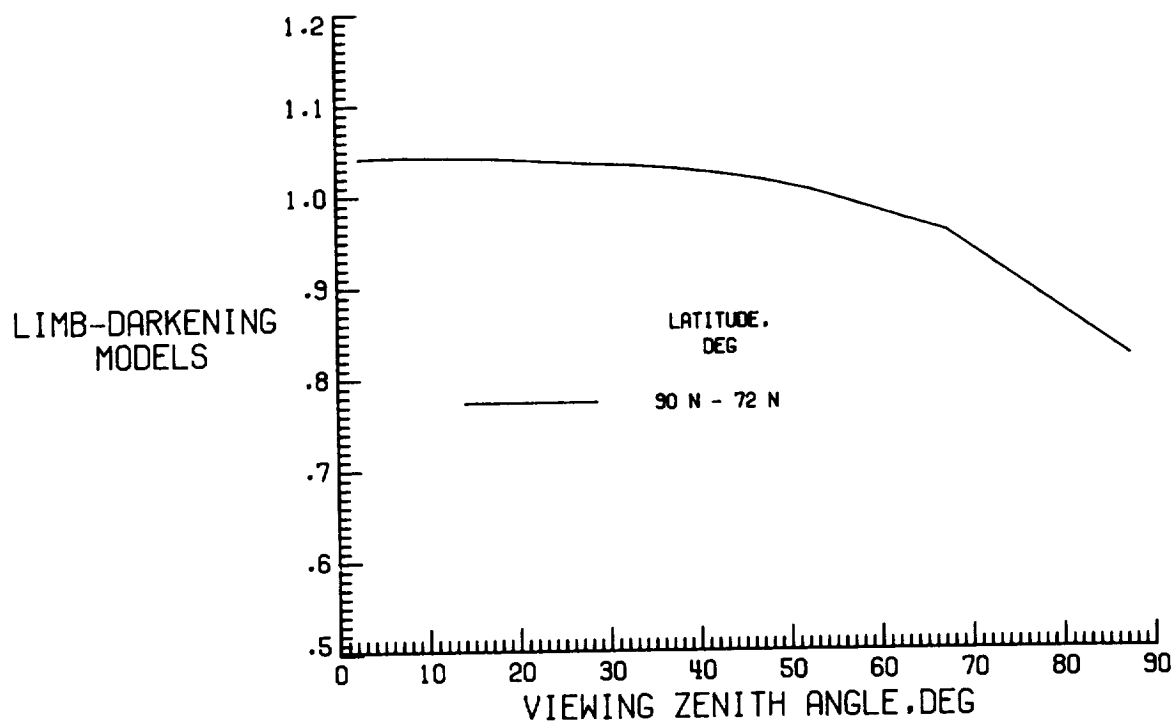


Figure 31. Limb-darkening models for mostly cloudy over land-ocean mix for day for NOAA-9.

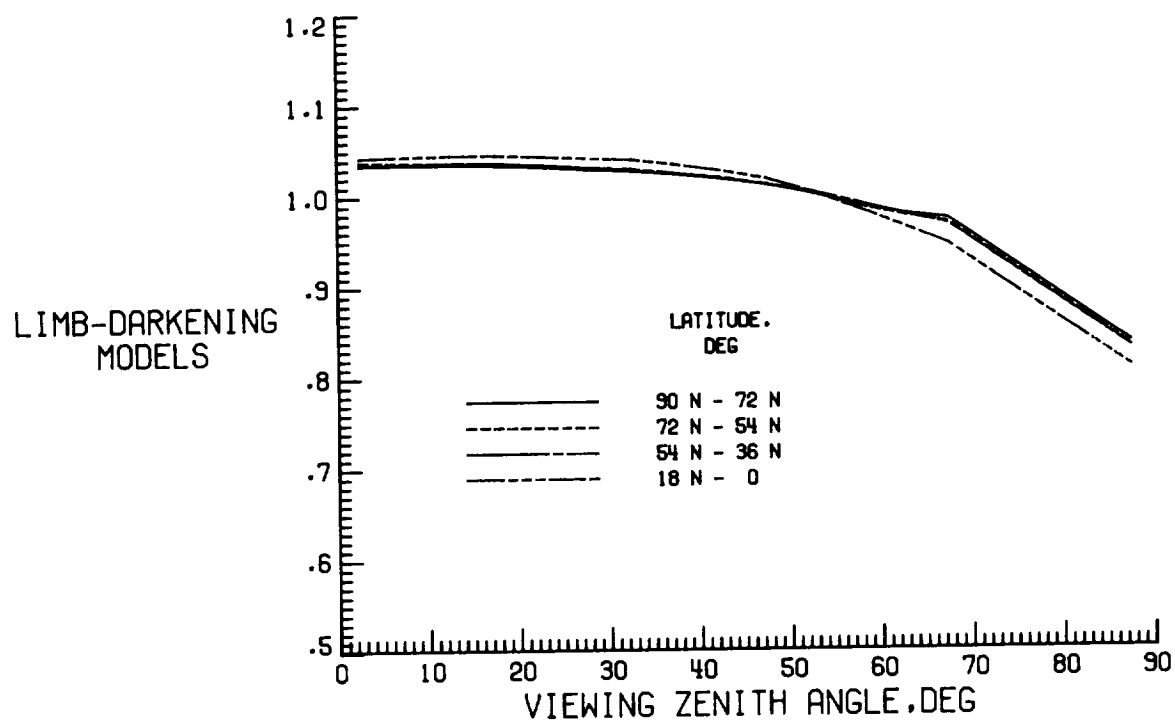


Figure 32. Limb-darkening models for overcast for day for NOAA-9.

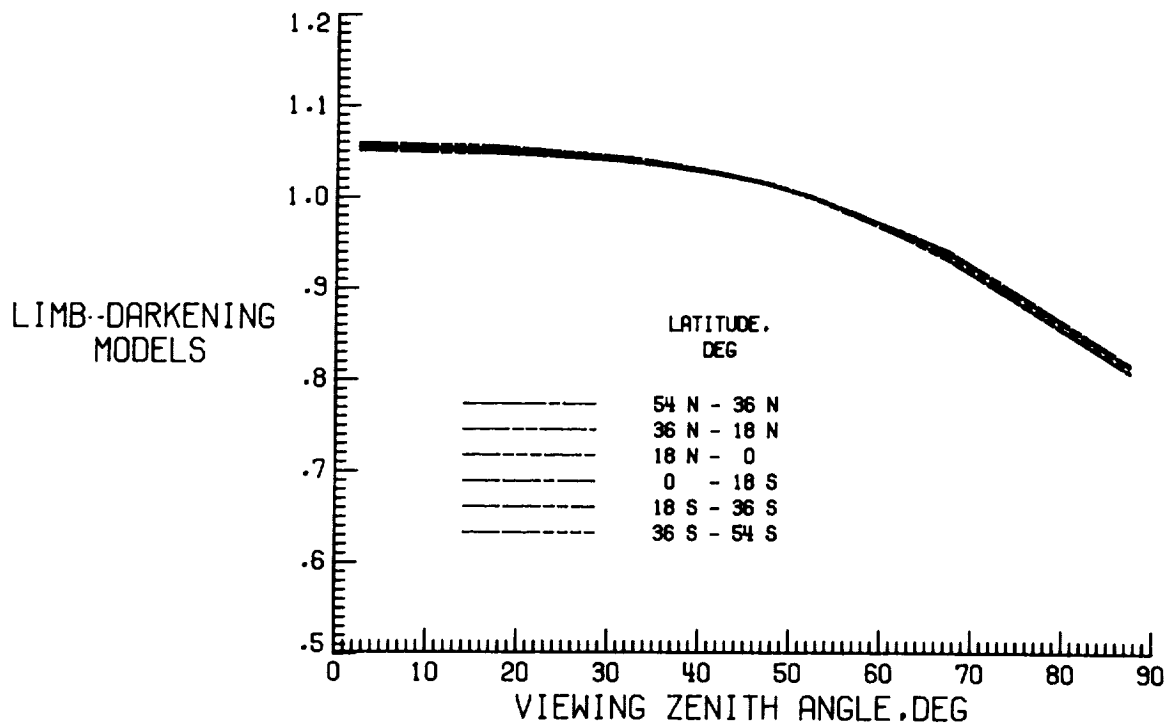


Figure 33. Limb-darkening models for clean ocean for night for NOAA-9.

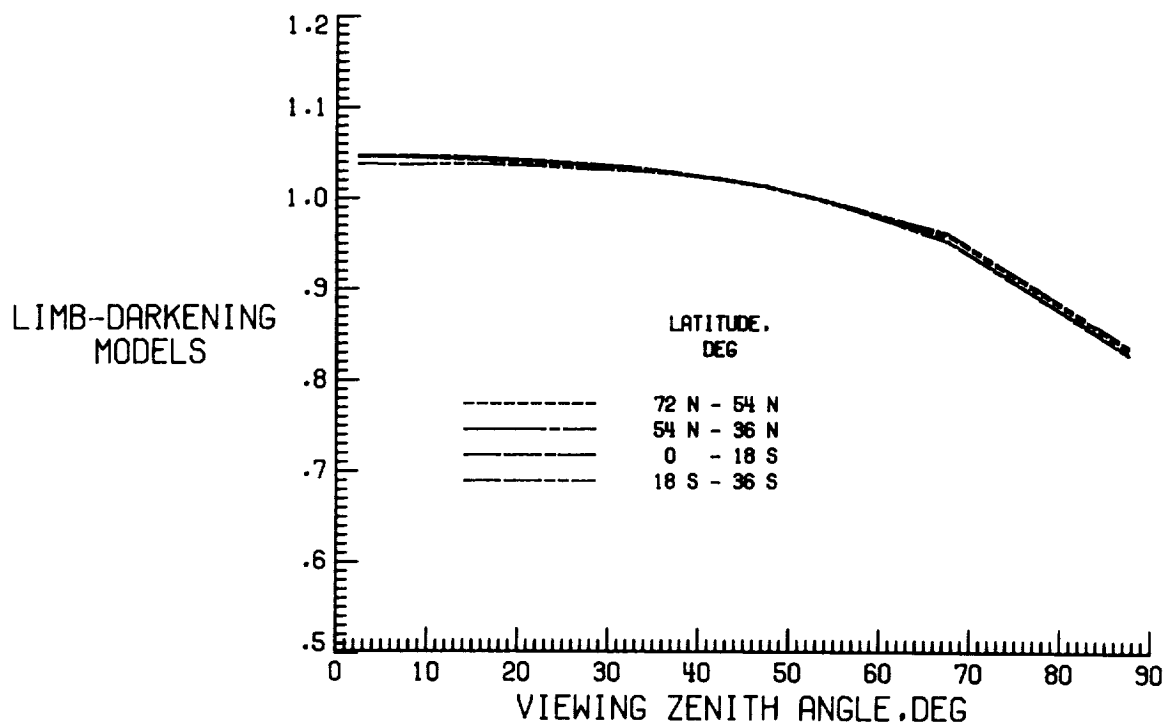


Figure 34. Limb-darkening models for clear land for night for NOAA-9.

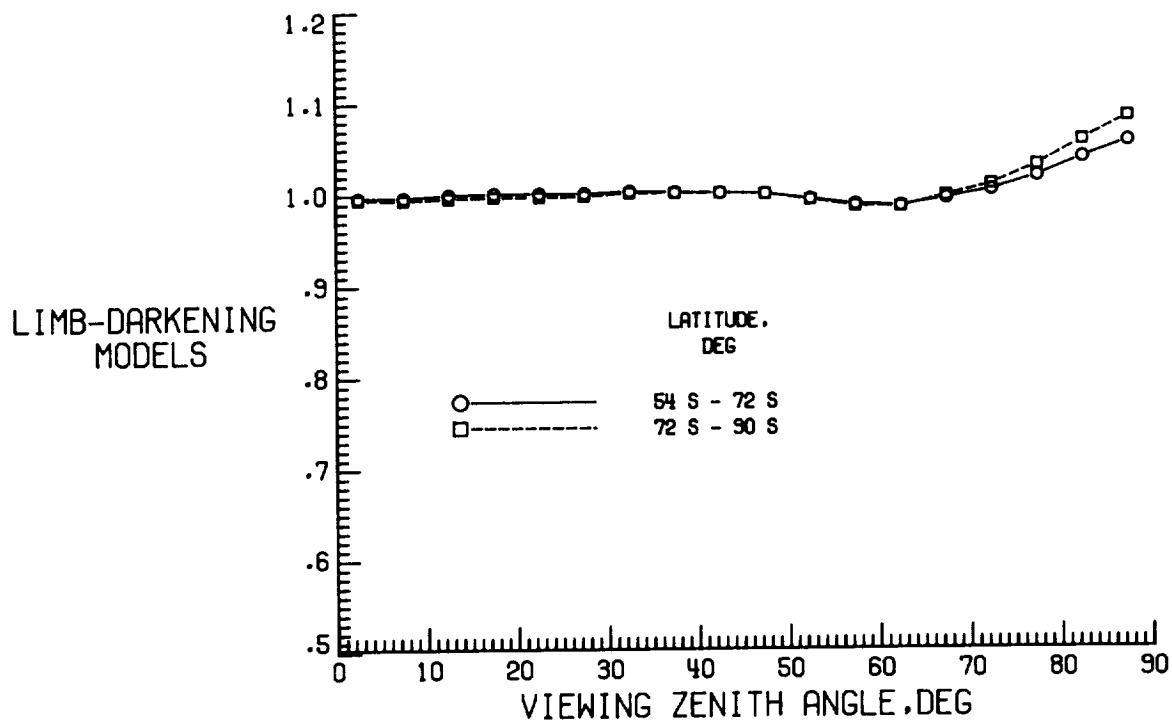


Figure 35. Limb-darkening models for clear snow for night for NOAA-9.

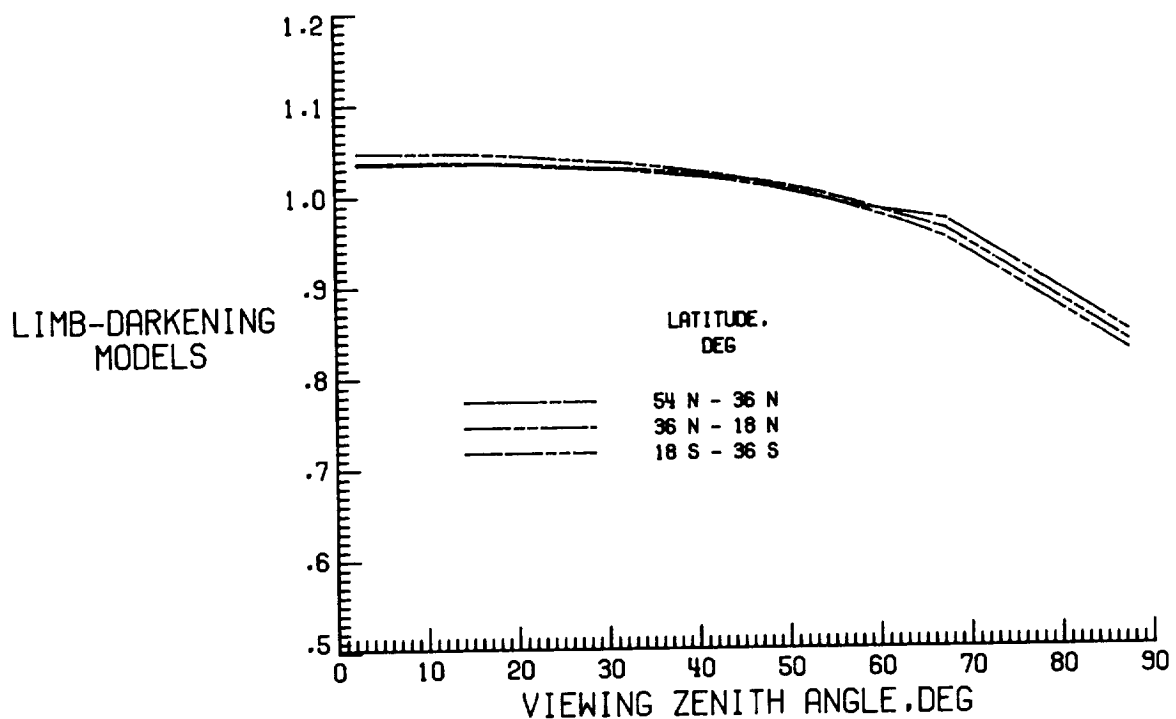


Figure 36. Limb-darkening models for clear desert for night for NOAA-9.

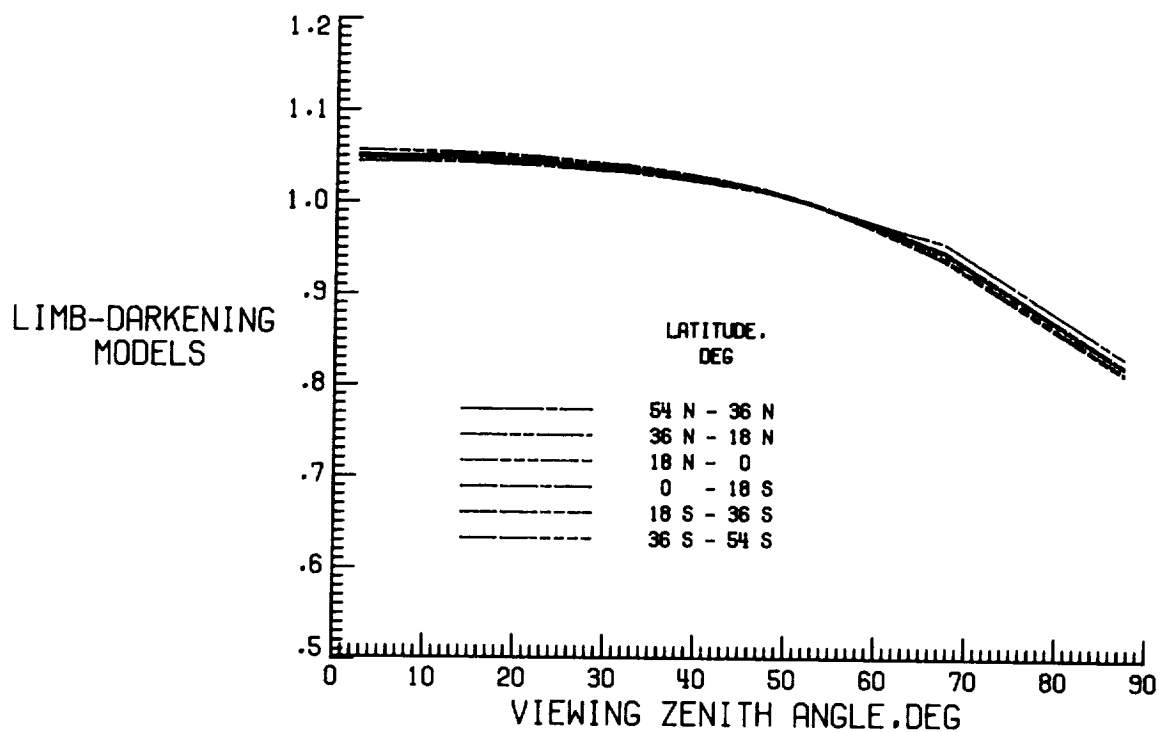


Figure 37. Limb-darkening models for partly cloudy over ocean for night for NOAA-9.

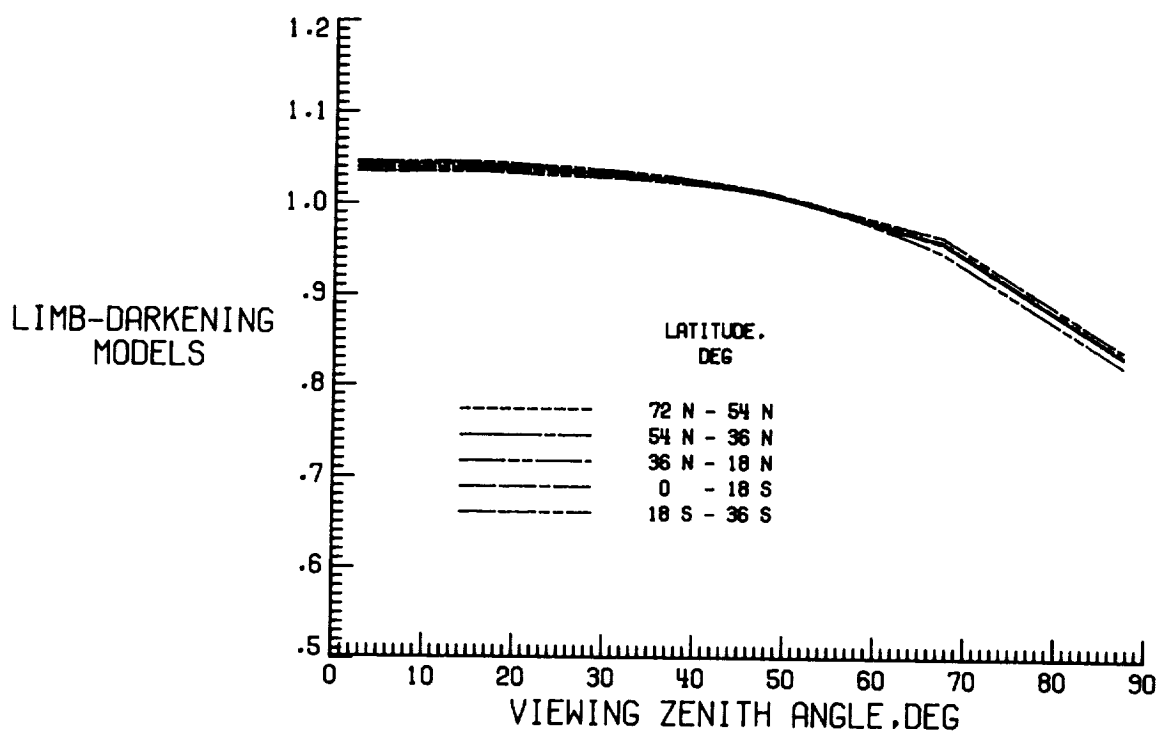


Figure 38. Limb-darkening models for partly cloudy over land for night for NOAA-9.



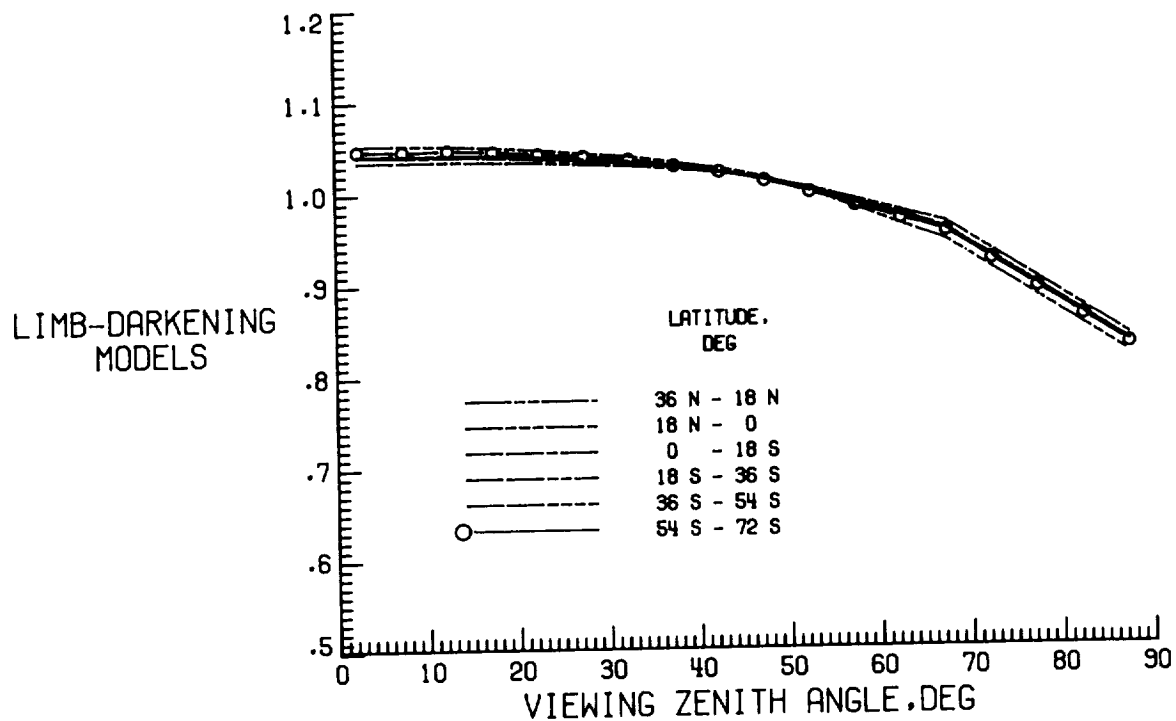


Figure 39. Limb-darkening models for mostly cloudy over ocean for night for NOAA-9.

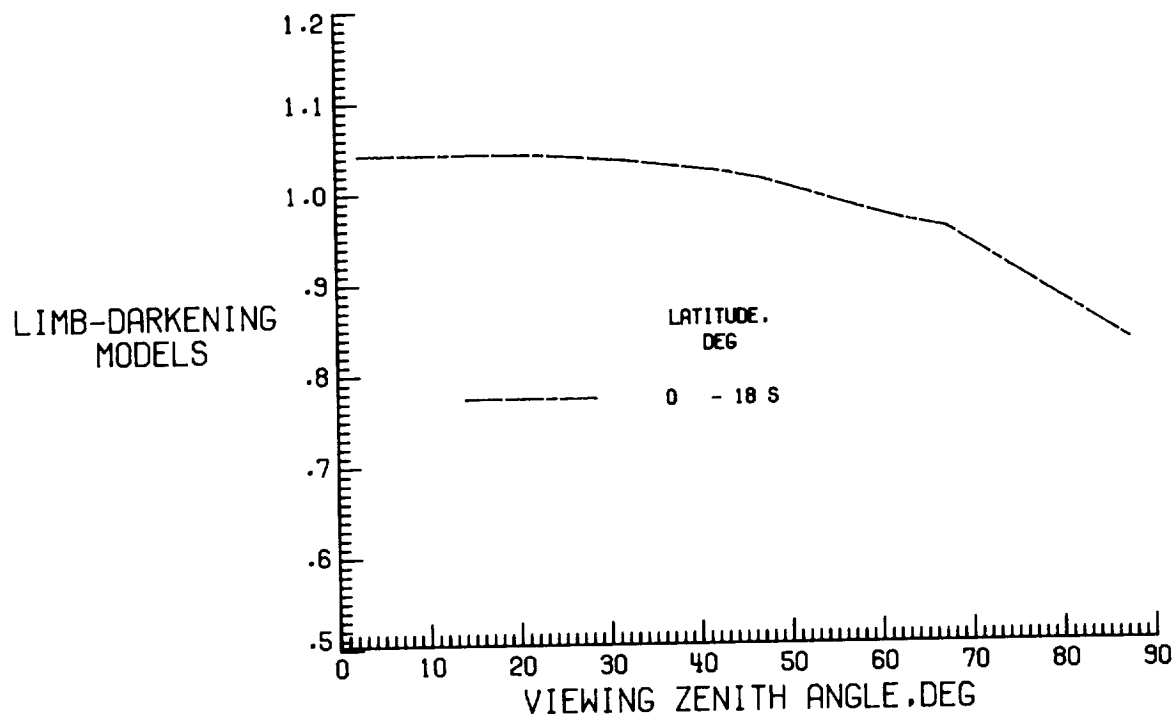


Figure 40. Limb-darkening models for mostly cloudy over land for night for NOAA-9.

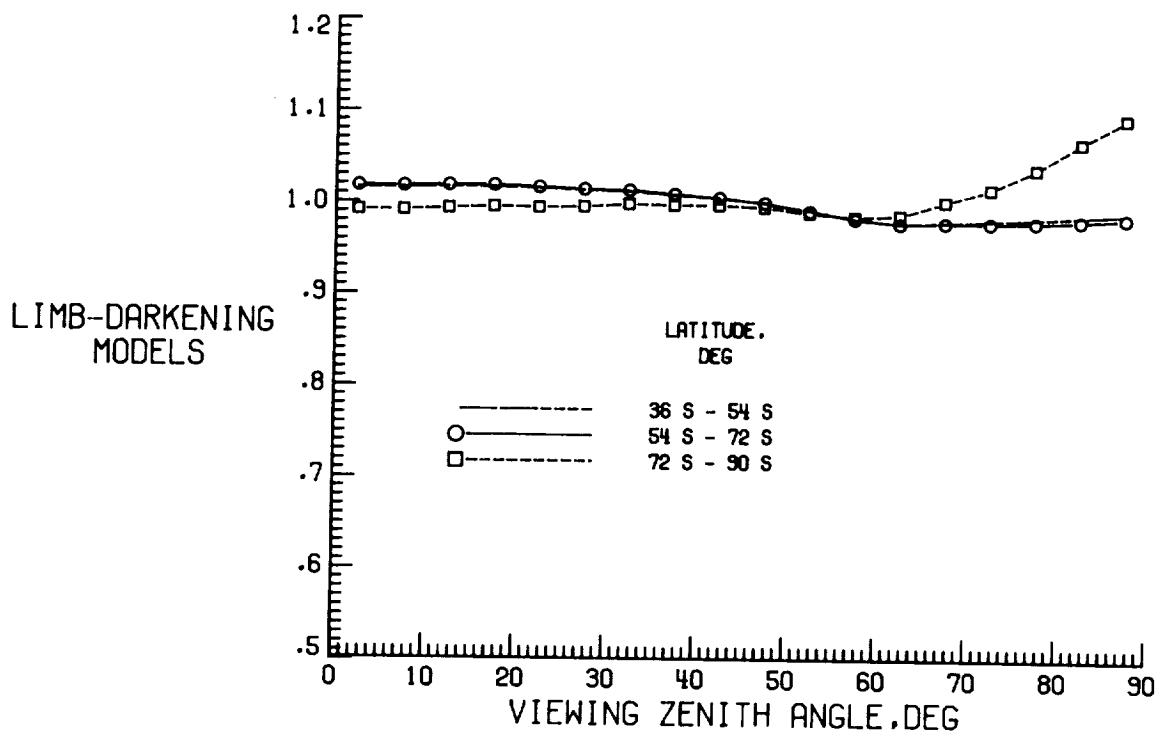


Figure 41. Limb-darkening models for overcast for night for NOAA-9.

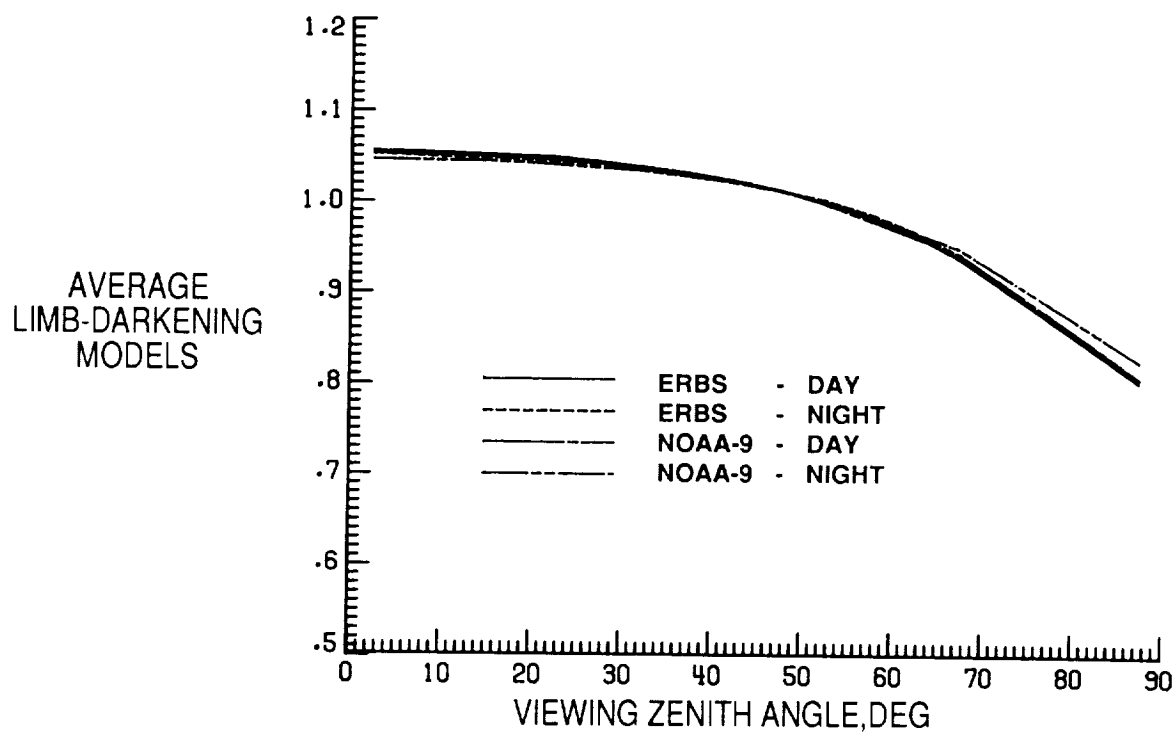


Figure 42. Average limb-darkening models for August 1985.



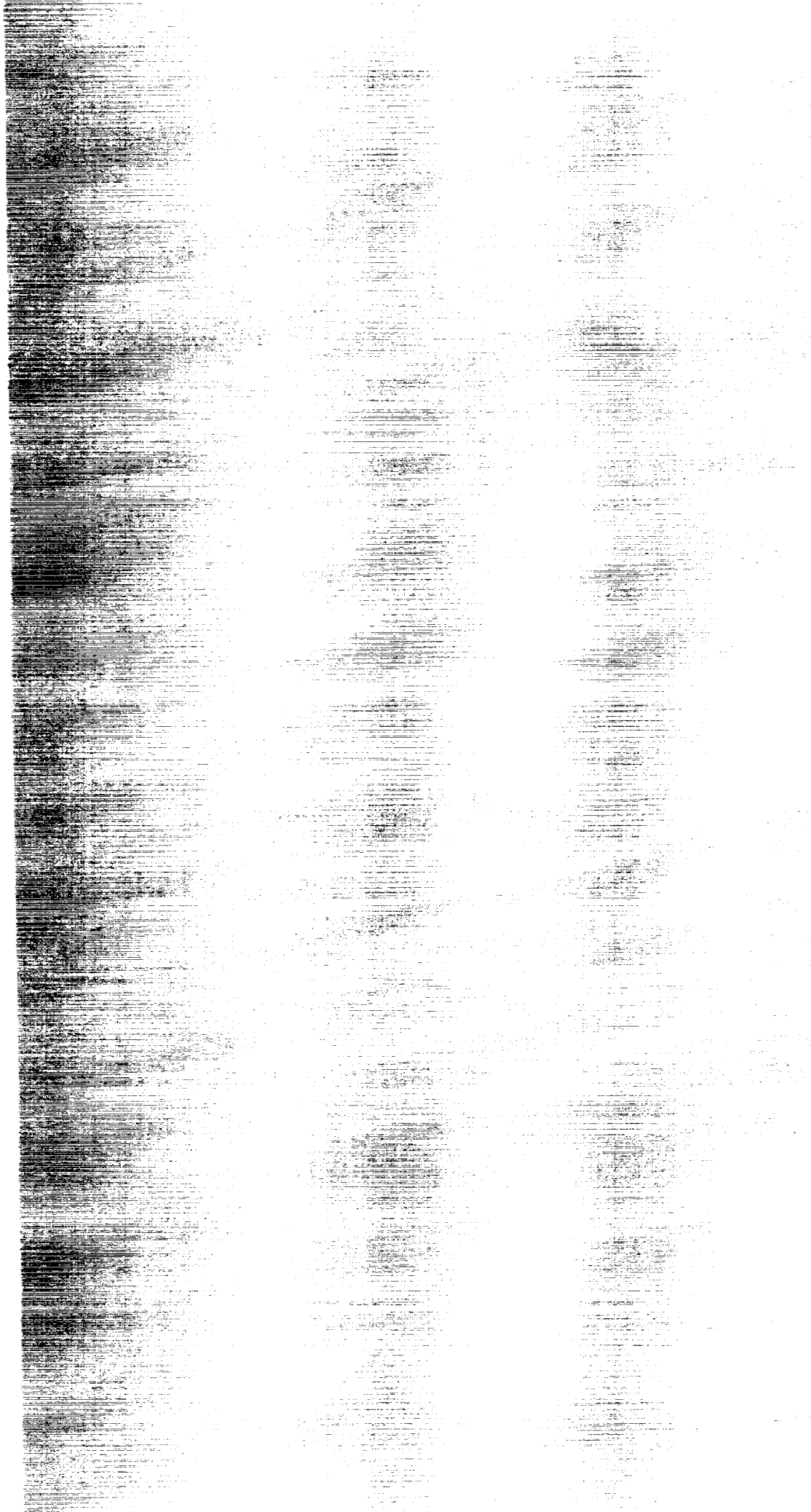




## Report Documentation Page

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16. Abstract During August 1985, the scanning radiometers of the Earth Radiation Budget Experiment aboard the Earth Radiation Budget Satellite (ERBS) and the NOAA-9 satellite were operated in along-track scanning modes. These data have been analyzed to produce limb-darkening models for Earth-emitted radiation, which relates the radiance in any given direction to the radiant exitance. Limb-darkening models are presented in tabular form and are shown as figures for day and night for each spacecraft. The scene types were computed with measurements within 10° of zenith. The models have values near zenith of 1.02 to 1.09, with values near 1.06 being typical. The typical value of the model is 1.06 for both day and night for ERBS, and the typical value at zenith is 1.06 for day and 1.05 for night for NOAA-9. Mean models are formed for the ERBS and for the NOAA-9 results and are found to differ less than 1 percent, with the ERBS results being the higher. The models vary about 1 percent with latitude near zenith. The present paper is a companion paper to NASA RP-1214, which reported limb-darkening models derived from January 1985 along-track operation of the scanning radiometer aboard the ERBS.			
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